AD-752 841

ILS (INSTRUMENT LANDING SYSTEM), FLIGHT, AND GROUND DATA FROM UNUSUAL EVENTS RECORDING SYSTEM IN A COMMERCIAL 737 AIRCRAFT

Larry E. Clay, et al

Technology, Incorporated

Prepared for:

Federal Aviation Administration

November 1972

DISTRIBUTED BY:

NTIS

National Technical Information Service
U. S. DEPARTMENT OF COMMERCE
5285 Port Royal Road, Springfield Va. 22151

REPORT NO. FAA-RD-72-113

ILS, FLIGHT, AND GROUND DATA FROM UNUSUAL EVENTS RECORDING SYSTEM IN A COMMERCIAL 737 AIRCRAFT

TECHNOLOGY INCORPORATED
INSTRUMENTS AND CONTROLS DIVISION
DAYTON, OHIO

NOVEMBER 1972

Final Report for Period July 1968 - August 1972

T.I. Project No. 273

FAA Contract No. FA68WA-1906

Availability is unlimited. Document may be released to the National Technical Information Service, Springfield, Virginia 22151, f [illegible].

PREPARED FOR

DEPARTMENT OF TRANSPORTATION

FEDERAL AVIATION ADMINISTRATION

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FAA-RD-72-113		

4. Title and Subtitle
ILS, Flight, and Ground Data from Unusual Events Recording Systems in a Commercial 737 Aircraft

5. Report Date
November 1972

6. Performing Organization Code

7. Author(s)
Larry E. Clay, Robert C. DeLong, and Ronald I. Rockafellow

8. Performing Organization Report No.
TI-273-72-2

9. Performing Organization Name and Address
Instruments and Controls Division
Technology Incorporated
3821 Colonel Glenn Highway
Dayton, Ohio 45431

10. Work Unit No.
182-742-027

11. Contract or Grant No.
FA68WA-1906

12. Sponsoring Agency Name and Address
Aircraft Division
Systems Research & Development Service
Federal Aviation Administration
Washington, D. C. 20590

13. Type of Report and Period Covered
Final Report
July 1968 - August 1972

14. Sponsoring Agency Code

15. Supplementary Notes
Details of illustrations in this document may be better studied on microfiche.

16. Abstract

To monitor the interaction between aircraft motion and pilot control inputs during such unusual happenings as upsets caused by turbulence and collision-avoidance type of maneuvers, Unusual Events Recording Systems (UERS) were installed in three jet transports--a Boeing 707, 727, and 737--operated by two major airlines in scheduled passenger-carrying flights. A total of 2088 hours of usable data recorded between September 1969 and April 1971 were presented in Interim Report FAA-RD-71-69. Then the recording program was modified and extended to record additional Instrument Landing System (ILS) parameters and ground data on the Boeing 737 during 6 months of operation. Between October 1971 and April 1972, 503 hours of data were recorded on 725 flights. Data results indicate that after localizer intercept the 737 aircraft during IFR approaches are operated with localizer deviations no greater than those for several aircraft types flying simultaneous IFR approaches to parallel runways as reported in Reference 6. During ground operation the highest accelerations (1.1g vertical and 0.8g lateral) were recorded at landing impact, and the maximum c.g. lateral accelerations in turns were below 0.3g. Average runway occupancy times were 33 seconds during departures and 32 seconds during arrivals. The presented data includes probabilities of exceeding flap and landing gear placard speeds, mean airspeeds and stall margins during IFR and VFR approaches, control deflection versus dynamic pressure envelopes, percentage of time in turbulence versus altitude, and distribution of c.g. vertical acceleration peaks.

17. Key Words
Unusual Events Recording System
commercial jet transports
ILS data
airline flight & ground data
Boeing 737 aircraft

18. Distribution Statement
Availability is unlimited. Document may be released to the National Technical Information Service, Springfield, Virginia 22151, for sale to the public.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
None	None	~~95~~ 105	3.00 P.C. 0.95 M.F.

Form DOT F 1700.7 (8-69)

PREFACE

The Instruments and Controls Division of Technology Incorporated, Dayton, Ohio, prepared this final report to document the procedures and results of the final period of the Unusual Events Recording System (UERS) recording program conducted on a Boeing 737 aircraft. Interim Report FAA-RD-71-69 documented the earlier phase of the program during which data was recorded on three Boeing Aircraft--a 707, a 727, and a 737. During the final period, the recording objectives were modified to add the acquisition of glide slope and localizer deviations during IFR approaches and taxi speed and accelerations during ground operation. The 24-channel UERS recorded 503 hours of usable data during 725 flights between October 1971 and April 1972. Of these flights, 45 included landings under IFR conditions.

The reported work was sponsored by the Aircraft Division, Systems Research and Development Service, the Federal Aviation Administration, under Contract FA68WA-1906. Messrs. Richard A. Kirsch and J. Clay Staples monitored the program for the FAA. The Technology Incorporated project engineer was Mr. Robert C. DeLong.

The authors gratefully acknowledge the support of the subcontractor airline which supplied the instrumented aircraft and collected the data. Also acknowledged is the support of the following Technology Incorporated personnel: Brian E. Arment, Gary E. Brazier, Charles L. Oakman, Sandra K. Buehler, and Susan E. Borland.

Preceding page blank

TABLE OF CONTENTS

Preceding page blank

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS - Continued

LIST OF ILLUSTRATIONS - Concluded

LIST OF TABLES

LIST OF TABLES - Concluded

1. INTRODUCTION

An Unusual Events Recording System (UERS) program was initiated by the Federal Aviation Administration (FAA) in July 1968 to monitor the interaction between aircraft motion and pilot control inputs during the normal operation and any unusual events of jet transport aircraft in scheduled air carrier operations. A data sample recorded on three Boeing jet transports -- a 707, 727, and a 737 -- was analyzed and documented in Reference 1.

In June 1971 the program was modified and extended to record additional Instrument Landing System (ILS) parameters and ground data on the Boeing 737 during 6 months of operation. Between October 1971 and April 1972, 503 hours of usable data were recorded on 725 flights.

The objective of the extended recording program was to provide, in addition to the unusual events monitoring, the following statistical data:

(1) ILS data during IFR approaches:

localizer and glide slope needle deviations versus distance from threshold.

(2) Approach speed data:

stall margin and airspeed variations during IFR and VFR approaches.

(3) Touchdown data:

accelerations, airspeed, stall margin, and pitch attitude at landing impact.

(4) Taxi data:

(a) time from touchdown and speed at thrust reverse and first wheel brake application, and maximum rpm during thrust reverse.

(b) lateral accelerations and taxi speeds during turns.

(c) acceleration peaks versus taxi speed.

(5) Flight data for control surfaces and deployable equipment:

(a) envelopes of control deflections versus dynamic pressure.

(b) dynamic pressure during flap and landing gear extensions.

(6) VGH data during flight operation:

c.g. vertical acceleration peaks and time in intervals of weight, airspeed, and altitude.

This final report contains the data for the 737 aircraft. In addition to the 1971-72 data, this report includes those types of the earlier 737 Normal Events and VGH data which are compatible with the current data to provide a more significant sample for the 737 aircraft.

The following sections briefly describe the UERS system, the instrumented 737 aircraft, the instrumentation installation, and the data collection; discuss in more detail the reduced data definitions; present the data results; and list the conclusions.

2. UNUSUAL EVENTS RECORDING SYSTEM (UERS)

The Unusual Events Recording System (UERS) consisted of the following major components: a Digital Adaptive Recording Set (DARS) with a compatible magnetic tape magazine, a signal conditioning unit, and various types of transducers. The signal conditioner converted the signals of various types of transducers to analog signals compatible with the digital recorder. The recorder sampled the analog signals, converted them to a digital value, edited these samples for redundancy, and transferred the digital samples to the tape magazine for permanent storage. Appendix II describes the major UERS components, and Reference 2 details the UERS design, fabrication, installation, and calibration.

3. INSTRUMENTED AIRCRAFT

During the current recording phase, a modified UERS recording system was installed in the originally instrumented Boeing 737 aircraft. This aircraft, one of three instrumented during the first phase of the program described in Reference 1, was operated in scheduled passenger-carrying service within the United States by an airline company. The 737 was selected for this recording phase because its short-haul operation promised the greatest number of instrument approaches and the most ground operation during the 6-month recording period.

Figure 1 shows a 737 aircraft, and Table 1 lists its physical data obtained from Reference 4.

4. UERS SYSTEM INSTALLATION

The recorder and signal conditioner on the instrumented 737 aircraft was installed in the aircraft's electronics compartment. For the later phase of the project, the following transducers were removed from the original installation: RMDI circuitry, OAT probe, cockpit vertical accelerometer, angle-of-attack probe,

TABLE 1. PHYSICAL DATA FOR 737 AIRCRAFT

Type of Service:	Short-haul
Propulsion:	Two JT8D-7's
Maximum Taxi Weight:	100,800 lbs.
Empty Weight:	59,650 lbs.
Wing Span:	93 ft.
Length:	100 ft.
Height:	37 ft.
No. of Passengers:	113

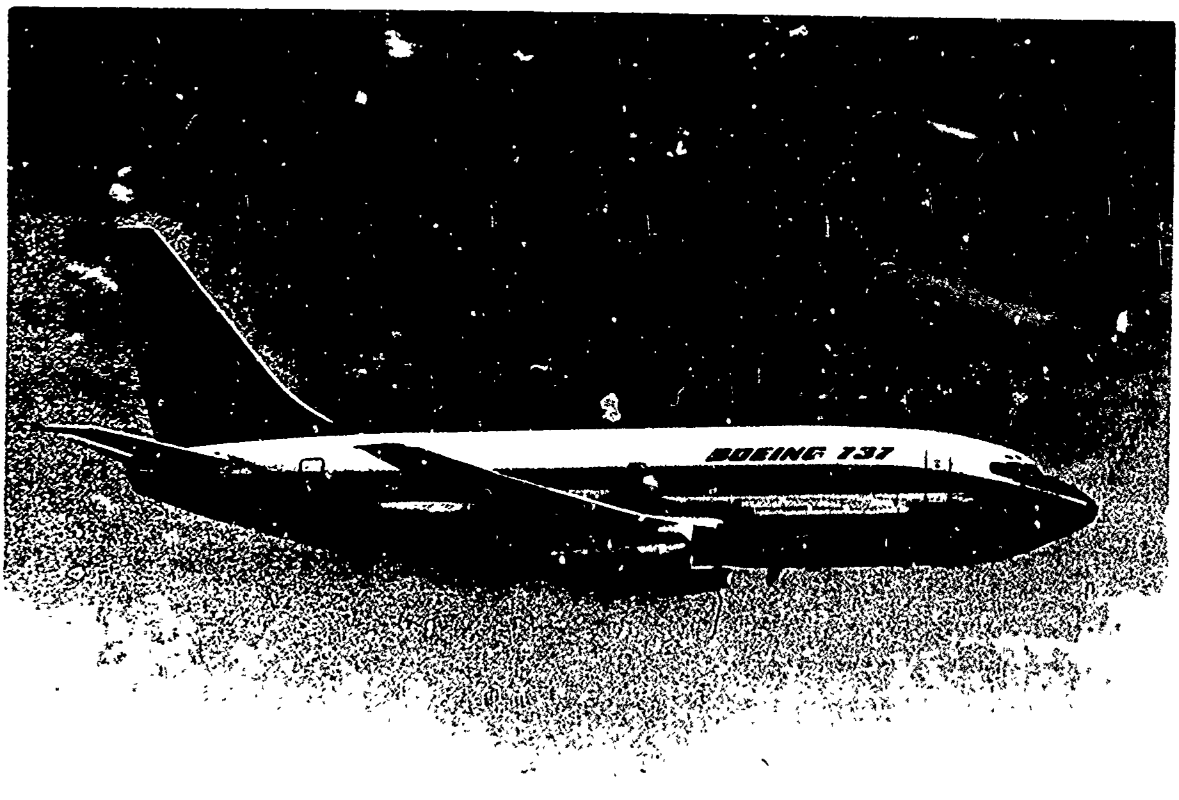


Figure 1. In-flight Photo of the Boeing 737 Aircraft

and angle-of-sideslip probe. These transducers were replaced with other transducers to record parameters of specific interest for this phase of the contract. Table 2 lists the parameters recorded by the modified UERS system. The following paragraphs describe the operation of the new transducers.

TABLE 2. LIST OF RECORDED PARAMETERS

Channel No.	Parameter	Channel No.	Parameter
1	Elevator Control Position	13	Static Pressure (Altitude)
2	Fuel Quantity	14	Heading
3	Engine No. 1 N_2 RPM	15	Differential Pressure Low (Airspeed)
4	Taxi Speed	16	Differential Pressure High (Airspeed)
5	C.G. Vertical Acceleration	17	Digital Switches (3)
6	Flap Position	18	Stabilizer Position
7(1)	DME (2)	19	Localizer Needle Deviation
8	Cockpit Lateral Acceleration	20(4)	Aileron Control Position
9	VOR Frequency	21	C.G. Lateral Acceleration
10	Engine No. 2 N_2 RPM	22	Marker Beacon
11	Roll Angle	23	Rudder Pedal Position
12	Pitch Angle	24	Glide Slope Bar Deviation

(1) Main landing gear touchdown shorts channel 7 to full scale.

(2) DME channel was disconnected to conserve magazine tape.

(3) The digital switches monitor the following functions:
Yaw Damper On — Autopilot in Roll-hold
Ground Spoilers Out — " " Pitch-hold
Landing Gear Down — " " Altitude-hold

(4) Wheel brake application shorts channel 20 to full scale.

The taxi speed was obtained by paralleling the output of the anti-skid transducer on the right outboard main landing gear. The transducer consisted of a 77-pole tach generator which emits 77 electrical pulses for each rotation of the wheel. The frequency of this signal is directly proportional to wheel rotation and aircraft taxi speed. Circuitry within the signal conditioner transformed this varying frequency signal to a dc level proportional to ground speed. The output of the signal conditioner was scaled to provide accurate data over the 5- to 65-knot range of taxi speed.

The wheel brake signal was obtained by installing adjustable microswitches on the linkage between the foot pedal and the brake actuator. These switches operated when the brake pedals were depressed by either the Captain or the First Officer of the aircraft. The sensitivity was adjusted during installation to require a firm depression of the brake pedal. The signal obtained from

the switches was used to deflect the recorded aileron channel signal to full scale when wheel brakes were applied.

The glide slope and localizer deviation signals were obtained by connecting conditioning circuits across the Captain's flight director. These signals were raw glide slope and localizer data obtained directly from the UHF receiver. The conditioned signals were scaled to require ±150 microamperes of glide slope deviation and ±200 microamperes of localizer deviation to swing the recorded signals from minimum to maximum. Thus, the recorded deviation data was identical to the raw data displayed at the bottom and right side of the Captain's flight director shown in Figure 2a and in the CDI shown in Figure 2b, except that the ±200 microampere localizer deviation range exceeded the ±150 microampere capability of the displays.

The marker beacon signal was obtained by connecting conditioning circuitry across the Captain's marker indicators. As the indicator lamps flashed, the outer marker signal deflected the recorded signal to a predetermined value, and the middle marker signal deflected the recorded signal 50 percent of the outer marker value.

The low-range airspeed signal was obtained by amplifying the dynamic pressure transducer signal by a factor of approximately 4. This allowed an airspeed signal up to 200 knots to be measured during approaches and departures. The high-range airspeed signal, with a range up to 430 knots, was obtained directly from the dynamic pressure transducer.

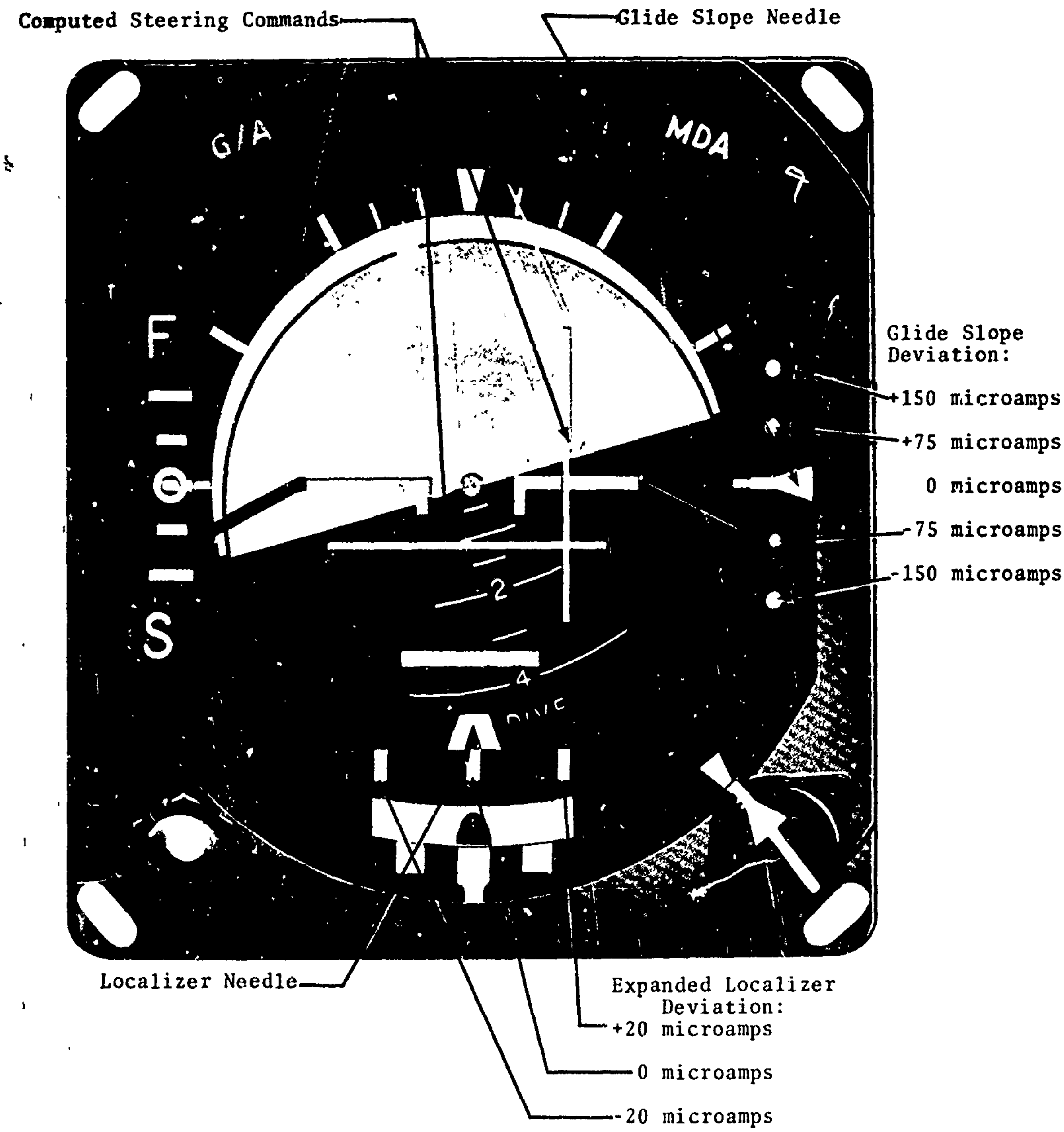
The instrumentation was calibrated before and during installation and during and after removal, and the calibration slopes were checked several times during the data collection phase A description of the calibration techniques and results are included in Table 17 in Appendix II.

During the recording program, the recorded DME information was quite noisy, and the recording capacity of the UERS magazines was severely reduced by the activity of this channel. Further, the number of arrival airports with VORTAC's which provided useful DME data during approach was too small to warrant the additional expense of this channel. Therefore, the DME channel was disconnected early in the recording period.

5. DATA COLLECTION

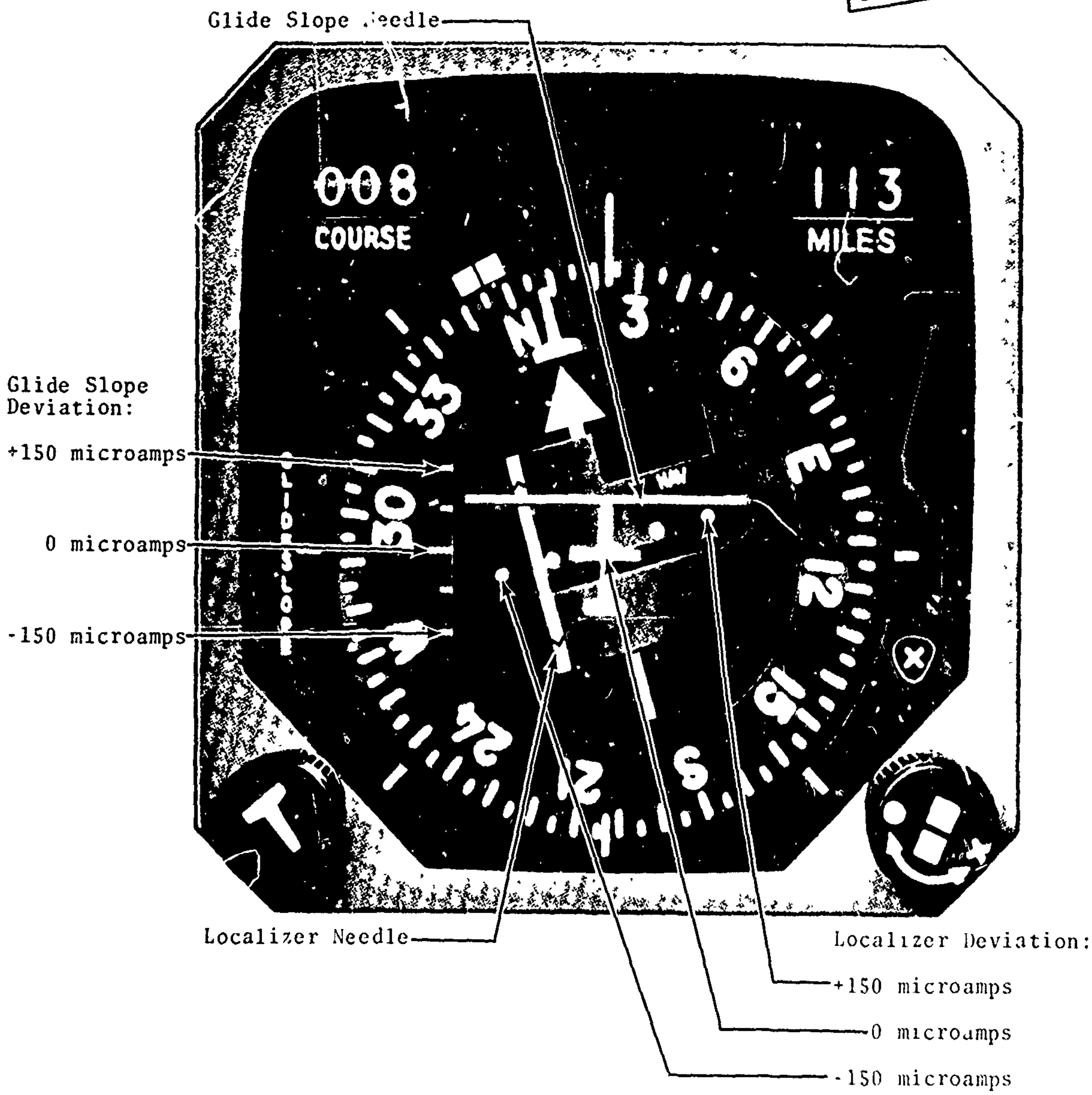
The data collection arrangements by the airline company during this recording phase were a continuation of those set up during the original recording period and described in Reference 1. At predetermined checkpoints, airline maintenance personnel performed UERS system checks and noted the percentage of recording tape remaining. When the percentage of tape remaining was below 10 percent, the magazine was removed and replaced with a fresh

one. The expended magazine, along with a report on the time and date of magazine change, was sent to Technology Incorporated. Because this phase recorded more ground operation time per flight, the time between magazine changes was reduced to 2 days during this recording period.



(a) Attitude Director Indicator
(Sperry Flight Systems Division Model HZ-6B)

Figure 2. View of the 737 Aircraft Cockpit Indicators with Recorded Glide Slope and Localizer Deviations Indicated



(b) Master Heading Pictorial Deviation Indicator (Sperry Flight Systems Division Model MHR-4A)

Figure 2 - Concluded

The subcontracted airline furnished computer tabulations with the airport identification and time for each recorded departure and arrival along with the aircraft departure weight.

To permit classifying the approaches as IFR (Instrument Flight Rules) or VFR (Visual Flight Rules), the weather information for each arrival was extracted from the Hourly Weather Station Observation Reports supplied by the National Climatic Center in Asheville, North Carolina. These reports included ceiling, visibility, wind velocity, and gust velocity.

The data collection period extended from October 1971 to April 1972. Table 3 summarizes the data recorded during this period.

TABLE 3. RECORDED DATA SUMMARY

No. of Magazines with Valid Data:	37
No. of Magazines with Invalid Data:	
N_2 Channel Inoperative -	3
Recorder Power Switch Malfunction -	2
No Flight Data Recorded -	2
Total No. of Recorded Magazines:	44
Total No. of Flights with Valid Data:	748*
Average Flights per Magazine:	20

* Includes training flights and partially recorded flights which were not processed as VGH data. Total no. of flights in VGH data is 725.

6. DATA PROCESSING

When the UERS magazines were received at Technology Incorporated's Data Processing Center in Dayton, Ohio, the data was extracted by a playback unit connected to the company's computer. Then a series of programs processed and reduced the data into several general categories: VGH data, Normal Events data, ILS data, Taxi data, and Flaps versus Airspeed data. The definitions and computational procedures employed in the processing of the data are described in Appendix III.

Both the recorded input data and the processed output data were permanently stored on tape, and a complete copy of the output data tabulations was delivered to the FAA. The more significant data results are included in the following paragraphs.

7. DATA RESULTS

The data results are presented in graphical and tabular form in Appendix I. The 737 data from Reference 1 was combined

with the current 737 data in all types of data presentations where the two sets of data were compatible. The following sections discuss the data results under general categories. Note that all ranges or intervals in the tabular data are represented by their lower limits; for instance, 0.7 indicates the n_z interval from 0.7g to 0.8g.

7.1 Unusual Events

No extreme flight attitudes were recorded during the 737 recording program. However, three noteworthy events were recorded: 1) a "hard" landing, 2) a missed approach, and 3) a short landing rollout with a high deceleration.

The "hard" landing had a 1.1g vertical acceleration at the aircraft center of gravity. Figure 3 (Appendix I) depicts the recorded time history of c.g. vertical acceleration during touchdown. The approach to this landing appeared normal with a 120-knot airspeed and a 40-degree flap setting. The highest vertical acceleration during touchdown for the 1122 twin-jet landings reported in Reference 5 was between 0.8g and 0.9g.

The data for the missed approach is presented in Section 7.2. The reported ceiling during this approach was broken clouds at 200 feet and overcast at 400 feet. Upon crossing the middle marker at the decision height, the pilot apparently did not have the airport in sight and executed a missed approach according to the procedure given in Reference 3. After this approach, the pilot proceeded to the next scheduled destination. The flight was listed as an "over-flight due to weather" in the routing information accompanying the recorded data.

The data for the short landing rollout is presented in Section 7.3. This landing was performed at a relatively low aircraft weight (78,800 pounds) on Atlanta Runway 09L. After touching down well within the normal touchdown zone and with a rapid deceleration, the pilot decided he could turn at a taxi exit about 3000 feet from the runway threshold. To perform this early turnoff, the pilot had to brake hard with a peak deceleration of about 0.4g. During all other recorded flights on this runway, the pilots used an exit about 1000 feet further down the runway.

7.2 ILS Data

Recorded glide slope and localizer deviations during the missed approach to Roanoke runway 33 are plotted in Figure 4. The small deviations indicate an accurate approach down to the middle marker. The small bump in the glide slope deviation at about 16,000 feet from the threshold was cross-checked with the recorded values of vertical acceleration and pitch attitude. Since these other parameters did not substantiate the bump, it was deduced that the bump in the glide slope deviation was a local anomaly in the glide slope beam probably caused by ground obstructions near the transmitter antenna. The plotted flight

path after crossing the middle marker was derived from the recorded airspeed, heading, and altitude.

Forty-five flights during IFR weather conditions yielded valid localizer deviation data. Of these flights, thirty-five also had valid glide slope deviation data. Deviation data were plotted for eight runways which were selected as typical because of the number of recorded approaches or as unique because of the runway arrangement or the ILS equipment. The plotted data is presented in Figure 5. As expected, the glide slope deviations generally indicated a level approach until intercept of the glide beam centerline just before reaching the outer marker. The distance between the threshold and the outer marker of these runways varied from 3.6 to 5.1 nautical miles. With the exception of three of the approaches, the localizer deviations were relatively low from the outer marker to threshold.

A localizer back-course approach to Atlanta runway 27L under IFR conditions is illustrated in Figure 5a. Figure 5c shows data for an approach to the right runway of the parallel runways at both Midway and Atlanta airports.

Four of the recorded flights had a series of approaches and landings performed during 737 crew training. Eight of these approaches were made on an ILS runway with the glide slope and localizer receivers operating. It was assumed that these were simulated IFR approaches. The glide slope and localizer deviations during these IFR training approaches are presented in Figure 6. In general, this training data reflected greater precision than the operational IFR approach data.

When defined as the mean deviation plus three sigma of the distribution of recorded deviations, the normal operating zone for the 737 IFR, VFR, and Training data and for the simultaneous IFR approaches documented in Reference 6 is illustrated in Figure 7.

The localizer deviation data is summarized in Figure 7A. From 4 miles out to threshold, the lateral operating zones derived from the 737 IFR localizer deviations are almost identical to those defined by radar data recorded during simultaneous IFR approaches. Beyond 5 nautical miles the recorded 737 data indicates extreme variations because the recorded data frequently included part of the turn preceding the localizer intercept near the outer marker. From the Reference 6 data, all recorded at Chicago O'Hare Airport, the approaches had generally the same angular deviations or the same localizer deviations for at least 9 nautical miles from touchdown. Such deviations would be expected since the Instrument Approach Procedures (Reference 3) requires localizer course intercepts beyond 12 nautical miles on runway 14L and beyond 8.6 nautical miles on runway 14R for simultaneous parallel approaches. Thus, for the portion of the approach where the pilots are required to fly the localizer course, the lateral deviations and the normal operating zones are

the same for the 737 IFR approaches to a number of airports as for the simultaneous approaches to Chicago O'Hare Airport. Included for comparison, the data for the VFR approaches performed with the ILS receiver show a wide dispersion at all distances beyond 2 nautical miles from threshold.

The glide slope deviation data is summarized in Figure 7B. For the IFR approaches, the normal vertical operating zone covered almost the entire ±0.7 degree width of the beam thickness at all points from 1 to 8 nautical miles. The IFR training data indicated a slightly smaller operating zone, whereas the VFR data was again widely dispersed. No vertical deviations were given for the simultaneous approaches in Reference 6. The thickness of the normal vertical operating zone for IFR operation was greater than expected. This was probably caused by the pilot using a visual approach as soon as he had the airport in sight. However, the point at which the pilot made visual contact could not be reliably determined from the reported ceiling because of variations in the type of cloud cover present.

The maximum localizer overshoot between the point of initial intercept of the localizer centerline and the outer marker during each IFR approach was plotted in Figure 8. As seen from this figure, the mean localizer overshoot was 72.18 microamperes or about half of the full localizer needle deflection. From the data in Reference 6, it is estimated that the mean maximum overshoot for simultaneous IFR approaches was about 30 microamperes or about one-fifth of the full localizer needle deflection. Although part of this reduction in needle deflection during localizer overshoot is due to earlier localizer intercept, it is obvious that the pilots on parallel IFR approaches are more careful during localizer intercept to avoid large intrusions into the airspace between the extended runway centerlines.

Tables 4, 5, 6, 7, and 8 present, respectively, the localizer, glide slope, roll angle, indicated airspeed, and stall margin distributions versus distance from threshold for the IFR, VFR, and IFR Training approaches. The parameter values listed in the headings are the lower limits of the intervals.

At approach windows located at the outer marker, the middle marker, the threshold, and eight successive 6000-foot intervals from threshold, the simultaneous glide-slope and localizer deviations for each IFR approach were plotted on a grid to illustrate the dispersion of flight paths. These graphs are presented in Figure 9. Also shown on these graphs are dashed envelopes of the glide slope and localizer deviations defined by the mean value plus 3σ at each window. These graphs indicate a close grouping of the plots from the middle marker out to 24,000 feet from threshold. The point at the extreme upper left at threshold was recorded during the climbing left turn on the missed approach.

7.3 Airspeeds and Stall Margins During Approach

Airspeeds and stall margins were listed in Tables 7 and 8 for those approaches with the ILS receiver turned on. In Figures 10 and 11, time histories of mean airspeeds and mean stall margins are plotted for the flight rule, ceiling, and wind correction categories. In addition to the current 737 aircraft data, these graphs include the 737 aircraft data recorded earlier in the program.

Figure 10a compares the mean IFR approach airspeeds with the mean VFR approach airspeeds. As expected, the aircraft maintained a steadier airspeed for a longer approach under IFR conditions than under VFR conditions.

In Figure 10b the IFR approach airspeeds in the current data are compared in each ceiling category with those in the composite 737 data (including the earlier 737 data). The lowest and steadiest airspeeds were recorded in the 400- to 1000-foot ceiling category, which also contained the most recorded flights.

The IFR approach airspeeds in wind and gust correction categories are plotted in Figure 10c. In general the 0- to 5-knot calm category had the lowest approach airspeeds; however, the small samples in the higher categories had the lowest airspeeds at some of the plotted times.

The VFR approach airspeeds in wind and gust correction categories are plotted in Figure 10d. During the last minute of the approach, the flights with the higher wind and gust corrections maintained higher airspeeds. The actual correction to the mean airspeeds was only about half of the correction value prescribed for each category.

Figure 11 contains four graphs of mean stall margins in the same categories used for the airspeeds. Figure 11a shows that the IFR final approaches were conducted at a stall margin of about 1.28, with touchdown at a stall margin of 1.20. The VFR approaches were at higher stall margins, but had no perceptible stabilized final approach value. There is no trend of mean stall margin with IFR ceiling category as shown in Figure 11b. Figures 11c and 11d for the IFR and the VFR approaches, respectively, show that stall margins increased as the wind and gust correction increased. Because of the small IFR samples in the higher correction categories, some of the mean stall margins in Figure 11c do not conform to this trend.

7.4 Touchdown Data

Probability plots representing the distribution of c.g. vertical acceleration, indicated airspeeds, stall margins, and pitch attitudes at touchdown are shown in Figure 12. Figure

12a presents the probability of exceeding each level of c.g. vertical acceleration for the 737 data and for twin-jet aircraft data taken from Reference 5. The mean touchdown accelerations were 0.37g for the 737 aircraft and 0.24g for the twin-jet aircraft. The probability of airspeeds being less than a given value during 737 aircraft landings is shown in Figure 12b. The mean indicated airspeed at touchdown was 113 knots. As shown in Figure 12c, the corresponding stall margin distribution has a mean of 1.20. The pitch attitude at touchdown varied from 0 to 10 degrees and had a mean value of 2.7 degrees.

7.5 Taxi Data

Grouped in this section are several types of ground data representing all preflight operation up to liftoff and all post-flight operation from touchdown to parking. Although presented above, the vertical accelerations at touchdown are also included in the landing rollout phase of taxi operation.

The times from touchdown to the initiation of thrust reverse (as indicated by increasing engine N_2 rpm) are distributed in Figure 13. The mean time to thrust reverse is 8.01 seconds, with 95 percent of the thrust reverses between 4 and 12 seconds after touchdown. As shown in Figure 14, the mean rpm level reached during thrust reverse was 84 percent.

The times from touchdown to first wheel brake application and the indicated airspeeds at this application are presented in Figures 15 and 16. The mean time from touchdown to wheel brake application was 7 seconds at a mean indicated airspeed of 103 knots. The distribution of times indicate an early brake application on most landings, but on 9 percent of the landings no brakes were applied until after 14 seconds.

To indicate typical deceleration during landing rollout, time histories of the ground track, taxi speed, and deceleration were plotted for nine arrivals at Atlanta. The ground track was determined by integrating taxi speed to compute taxi distance and by plotting distance versus heading. Minor adjustments were made to the touchdown point to align the ground track with one of the taxi exits from the runway. Taxi speeds above 65 knots were computed by subtracting the headwind velocity from indicated airspeed. The deceleration was computed by differentiating taxi speed with respect to time, and a smooth curve was drawn through the calculated deceleration points. Figure 17 presents this time history data for landings on Runways 09R, 09L, 27R, and 27L. As shown, the aircraft used several taxi routes to the parking area depending on the taxi exit from the runway. The short landing rollout described in Section 7.1 is shown in Figure 17b. The peak longitudinal deceleration during rollout was normally between -0.2g and -0.37g; however, the short landing rollout reached a peak value of -0.4g. The times of ground spoiler extension, wheel brake application, and thrust reverse are indicated on the graphs.

The average runway occupancy times for each runway were determined by dividing the total times in takeoff roll and landing roll by the number of takeoffs and number of landings, respectively. The results are listed in Table 9. Then average longitudinal decelerations during landings were determined by dividing the difference between the average touchdown groundspeed (airspeed minus average wind speed) and the average turnoff speed by the average runway occupancy times. The average longitudinal accelerations during takeoff were computed similarly with the assumption that the aircraft taxied into position and stopped prior to the takeoff roll. Average departure runway occupancy times for various runways ranged from 26 seconds to 59 seconds, with the overall average being 33 seconds. Average arrival runway occupancy times for the various runways ranged from 24 seconds to 70 seconds, with an overall average of 32 seconds. The longer runway occupancy times were the result of holding during departures and of airport arrangement requiring extended taxiing on the runway during arrivals. Since the average accelerations were based on runway occupancy times, the lower numbers do not represent the acceleration capability of the aircraft or the peak values recorded. These lower accelerations occurred at only a few runways, and the overall average accelerations adequately represent the overall 737 operation.

Figure 18 presents a distribution of the percentage of time in taxi speed intervals for preflight taxi, takeoff roll, landing roll, postflight taxi, and for a composite of all ground operations.

The distributions of the number of turns per departure and per arrival for each runway are listed in Table 10. From two to four turns per flight is normal with some flights having nine or more turns, the highest being 11 turns in a preflight taxi. The average number of turns per flight is 3.9 for preflight taxi and 3.3 for postflight taxi.

A joint distribution of taxi speed at the start of each turn and heading change is plotted in Figure 19. In most of the turns with initial taxi speeds above 20 knots, the taxi speed fell off rapidly before a large heading change was made. The 180- and 210-degree turns were performed during parking and during turns between the runway and a parallel taxiway. Consecutive turns were not separated unless they were in opposite directions or were separated by a straight-ahead taxi of 5 or more seconds duration.

Lateral accelerations at the aircraft c.g. during turns are plotted versus taxi speed in Figure 20 and versus heading change in Figure 21. In general, c.g. lateral accelerations were higher during turns at higher taxi speeds and did not vary much with heading change for turns of more than 30 degrees left or right.

Acceleration peaks experienced during ground operation are presented in Figures 22, 23, and 24 for c.g. vertical acceleration, c.g. lateral acceleration, and cockpit lateral acceleration,

respectively. These figures present for each taxi phase the cumulative frequency of incremental acceleration peaks per 1000 flights. To obtain these values, it was assumed that accelerations are symmetrical during ground operation, and therefore the frequencies of occurrence of positive peaks and negative peaks were averaged. Figure 22 shows that vertical accelerations were most severe during landing roll. During takeoff roll the vertical accelerations at levels below 0.3g were encountered about 70 percent as frequently as during landing roll, but the frequency falls off rapidly above 0.3g. The taxi phases contributed less than 10 percent of the peaks at all levels above 0.2g. Figures 23 and 24 indicate that the significant c.g. and cockpit lateral accelerations were recorded during landing roll. The large peaks were recorded during or shortly after touchdown and were probably the result of crosswind landings.

The acceleration data during ground operation was also plotted versus taxi speed in Figures 25, 26, and 27. All peaks at taxi speeds above 65 knots were grouped in a single interval because the taxi speed transducer range was 0 to 65 knots. The largest accelerations were at taxi speeds above 65 knots. However, some significant peaks were recorded in the taxi speed intervals between 15 and 40 knots.

7.6 Flight Data for Control Surfaces and Deployable Equipment

The recorded data for each flight was divided into ascent, cruise, and descent phases. To further group the data by airspeed, the ascent phase was divided into one segment extending from liftoff to 2 minutes after liftoff, and a second segment spanning the remainder of ascent. The descent phase was also divided into two segments separated at 2 minutes before touchdown. For each recorded flight segment, the maximum deflection of each control surface in both directions was associated with the airspeed and dynamic pressure at that time. Composite plots of these maximum control deflections versus dynamic pressure are shown in Figure 28. An envelope which contains 99.7 percent (3σ) of the deflections in each airspeed interval was also plotted on each graph.

Figure 28a indicates a symmetrical envelope of aileron control deflections with decreasing deflection magnitudes at the higher dynamic pressures. The elevator control deflection plot in Figure 28b indicates the large up deflections required at the low takeoff and landing speeds and the small down deflections associated with high cruise speeds. Because of the low rudder deflections, the scale was expanded in Figure 28c. The rudder deflections were normally symmetrical and were much smaller at high airspeeds. The stabilizer deflections in Figure 28d were those required for trim in each dynamic pressure interval.

The probabilities of exceeding each level of airspeed and dynamic pressure at the eight flap settings are presented in

Figure 29. A separate graph for each flap setting contains a curve for data recorded during extension of the flaps and a curve for data recorded during retraction of the flaps. The flap placard airspeed is indicated for each flap setting. The probability of exceeding the placard airspeed was about 0.001, or 1 in 1000, at each flap setting.

Dynamic pressures at landing gear extension are shown in Figure 30. The probability of exceeding each level of dynamic pressure is compared with the landing gear operating limit. The probability of exceeding the limit is about 0.0005, or 1 in 2000.

7.7 VGH Data

For flight in each altitude interval, the percentage of flight time spent in turbulence is plotted in Figure 31 for the current data, for 737 data from Reference 1, for the composite of all 737 data, for the twin-jet data in Reference 9, and for the design criteria data from NACA TN 4332 (Reference 8). The amount of 737 data in the altitude intervals above 30,000 feet did not warrant consideration in this figure. Comparison of the data from the different sources shows that the 737 aircraft experiences more time in turbulence than the other aircraft. This is a result of the short-haul operations of the 737 aircraft which forces the aircraft to operate at low altitudes in rough air when aircraft flying longer routes could operate above the rough air. Comparison of the two sources of 737 data indicate that the Reference 1 data which was recorded mostly in the summer and fall contained more time in turbulence than the current data which was recorded during winter and early spring.

The recorded c.g. vertical acceleration peaks were placed in two categories--turbulence-induced and maneuver-induced. As shown in Figure 32, the turbulence peaks were encountered 10 times as frequently as the maneuver peaks. The acceleration peaks, classified by flight phase, are presented in Figure 33. During ascent and descent, the aircraft had roughly equal acceleration peak distributions; and during cruise, the acceleration peak frequency was about half that for ascent and descent. Composite curves showing the cumulative frequency per 1000 flight hours are presented in Figure 34 for 737, 707, 727, and twin-jet (Reference 9) aircraft. The acceleration peak spectrum of the 737 aircraft is the most severe because of its relatively low-altitude type of operation.

The current VGH data was combined with the earlier 737 data from Reference 1 for presentation in Tables 11 through 15. Tables 11, 12, 13, and 14 list c.g. acceleration peaks in intervals of normal load factor n_z and coincident airspeed, altitude, and weight intervals and flight phases, respectively. Table 15 presents a distribution of normal load factors for maneuvers and turbulence in each altitude interval.

8. SUMMARY AND CONCLUSIONS

(1) Airborne equipment recording ILS deviation data provides approach information comparable with that obtained from ground-based approach radar. The usable range of the ILS deviation data is about ±0.7 degrees about the glide slope centerline and ±3 degrees about the localizer centerline.

(2) Between the outer marker and threshold, the recorded IFR approaches by the 737 aircraft were flown with the same lateral precision as earlier simultaneous IFR approaches by several types of aircraft to parallel runways. In terms of localizer needle deflection, the maximum localizer overshoot during initial localizer intercept is only half as great during the simultaneous IFR parallel approaches (Reference 6) as during normal IFR approaches of the 737 aircraft.

(3) The ILS and airspeed data confirmed that longer, more stable final approaches were made during IFR approaches than during VFR approaches.

(4) For ground operations, the highest c.g. accelerations, 1.1g in the vertical direction and 0.6g in the lateral direction, were recorded during touchdown. The cockpit lateral acceleration reached 0.8g during one landing.

(5) Turns during taxi did not produce c.g. lateral accelerations above 0.3g.

(6) During recorded arrivals the average runway occupancy time was 32 seconds, and the average deceleration was estimated at 0.16g. During departures the average runway occupancy time was 33 seconds and the average acceleration was 0.20g. These values varied significantly from airport to airport and from runway to runway.

(7) Wheel brakes were normally applied within 6 seconds after touchdown and thrust reverse at about 8 seconds after touchdown.

(8) No unusually large control deflections were recorded at any level of dynamic pressure.

(9) The recorded flap versus airspeed data indicates that the 737 aircraft exceeded its flap placard speed at each flap setting at a rate of about once per thousand landings.

(10) The percentage of 737 aircraft time in turbulence was lower for the current winter-spring recording period than for the earlier summer-fall recording period.

APPENDIX I

FIGURES AND TABLES FOR 737 DATA

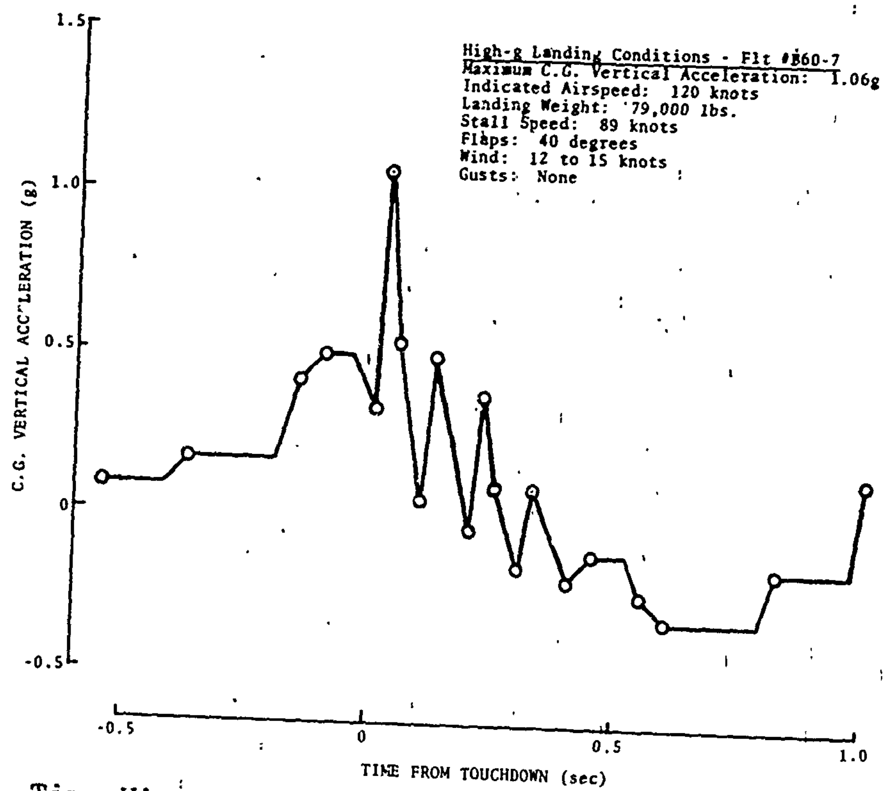


Figure 3. Time History of C.G. Acceleration During a Hard Landing

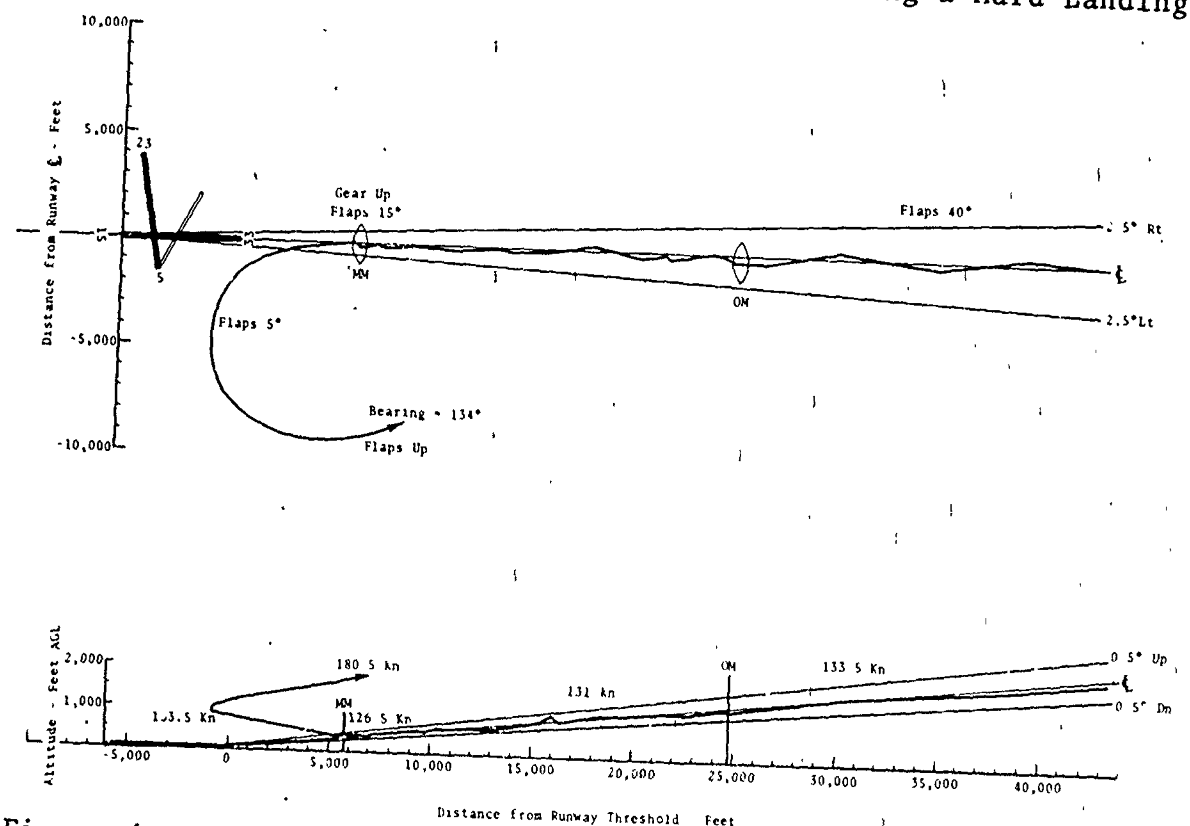
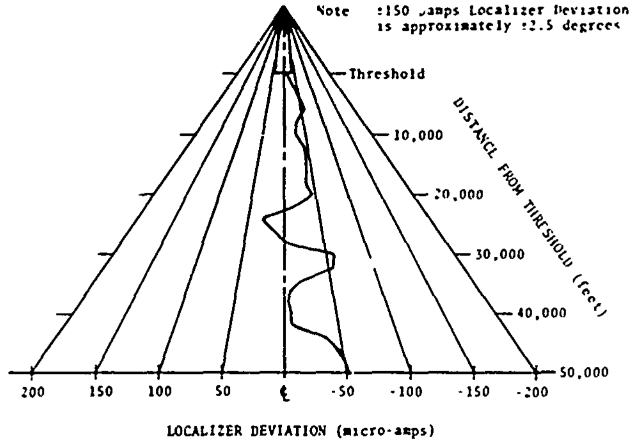
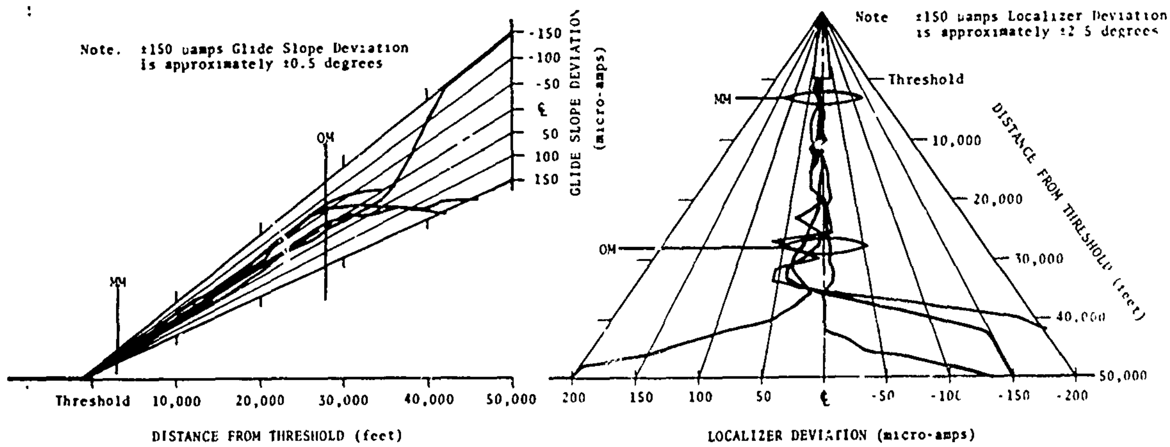


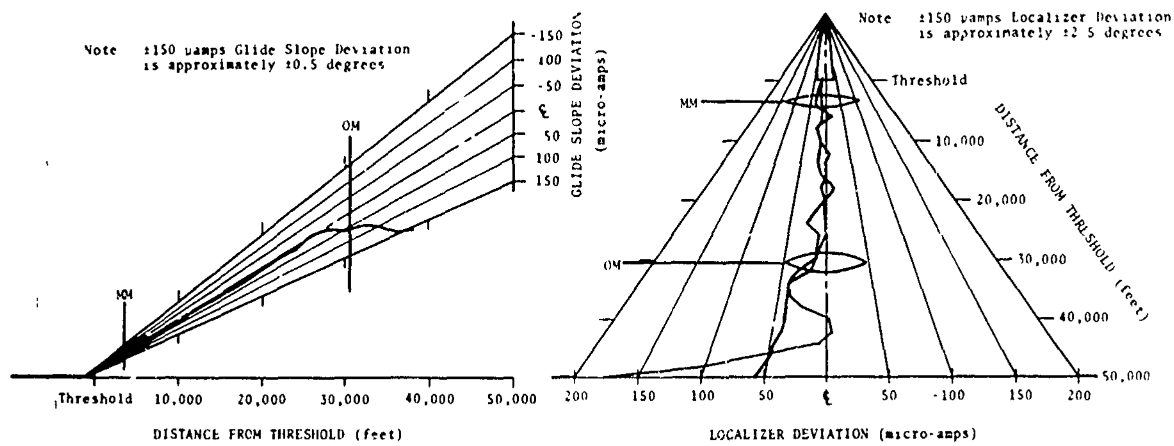
Figure 4. Localizer and Glide Slope Deviations During a Roanoke Approach Terminated Because of Weather



(a) Atlanta (ATL) - Runway 27L Localizer Backcourse

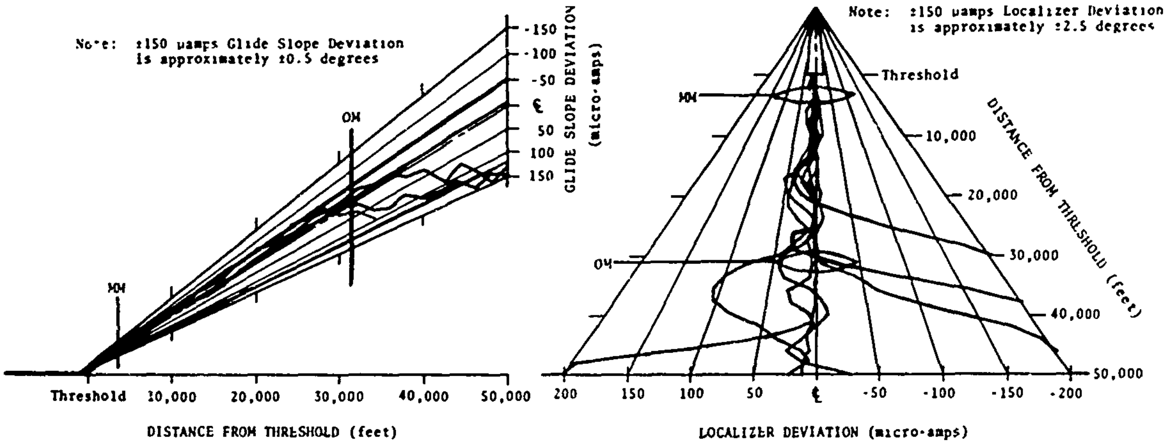


(b) Charlotte (CLT) - Runway 05 ILS

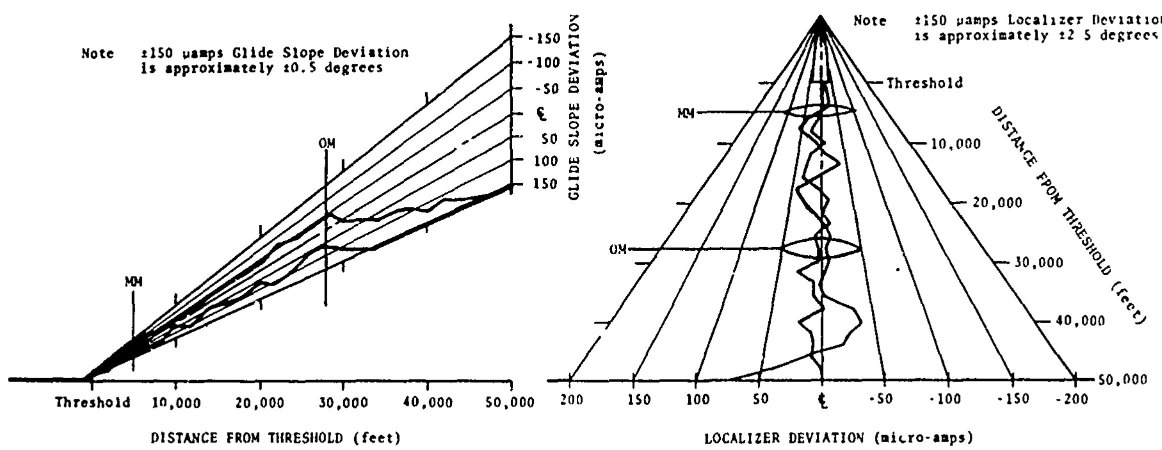


(c) Chicago (MDW) - Runway 13R ILS and Atlanta (ATL) - Runway 9R ILS

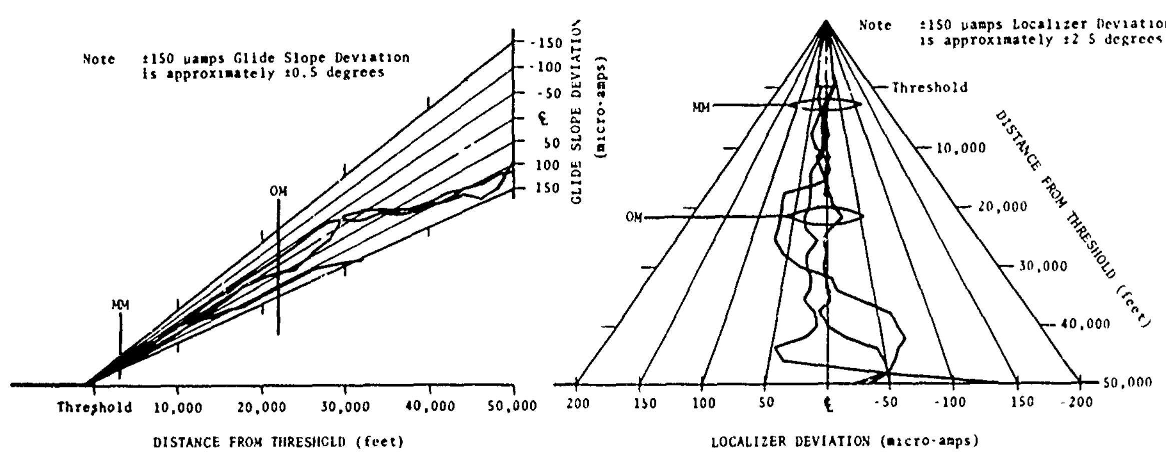
Figure 5. Localizer and Glide Slope Deviations During IFR Approaches



(d) Fayetteville (FAY) - Runway 03 ILS

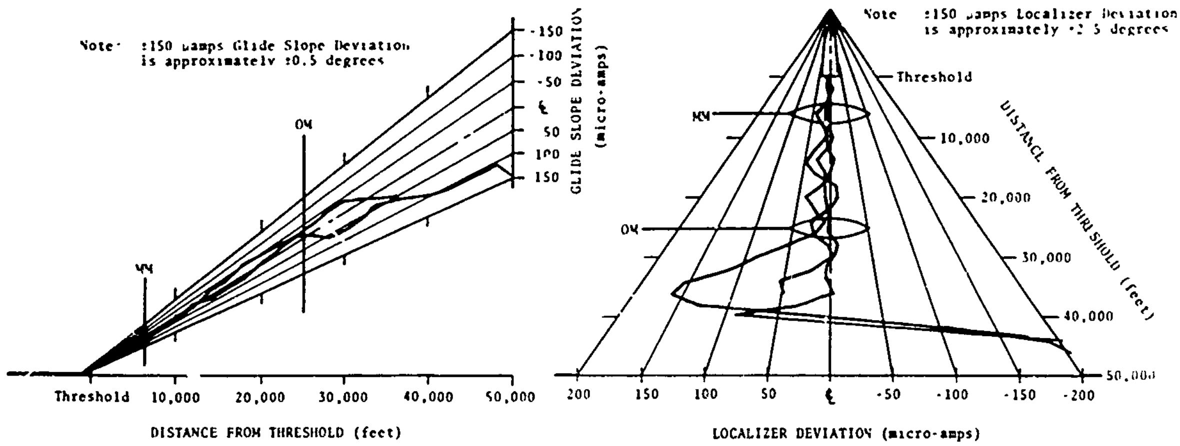


(e) Huntington (HTS) - Runway 11 ILS

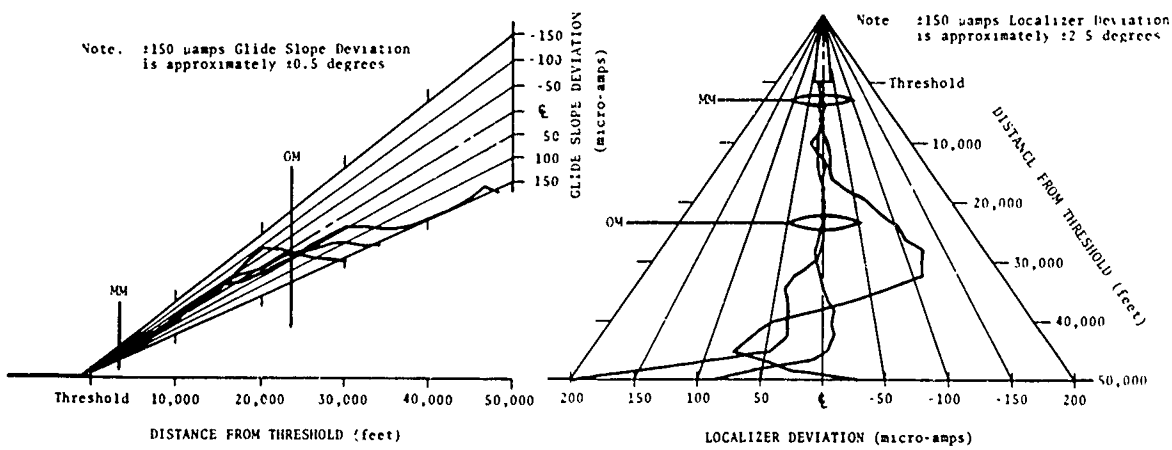


(f) · Norfolk (ORF) - Runway 04 ILS

Figure 5 - Continued



(g) Richmond (RIC) - Runway 33 ILS



(h) Winston-Salem (INT) - Runway 33 ILS

Figure 5 - Concluded

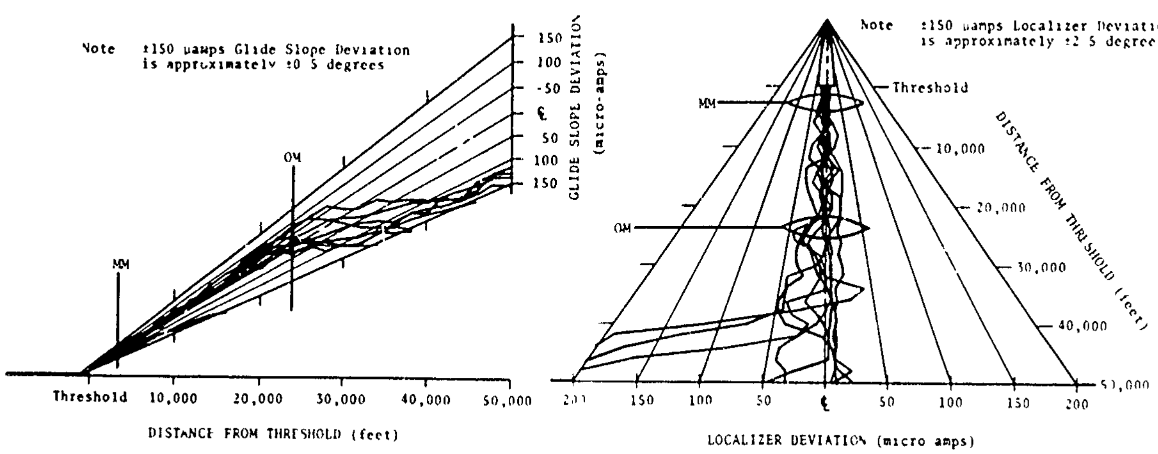
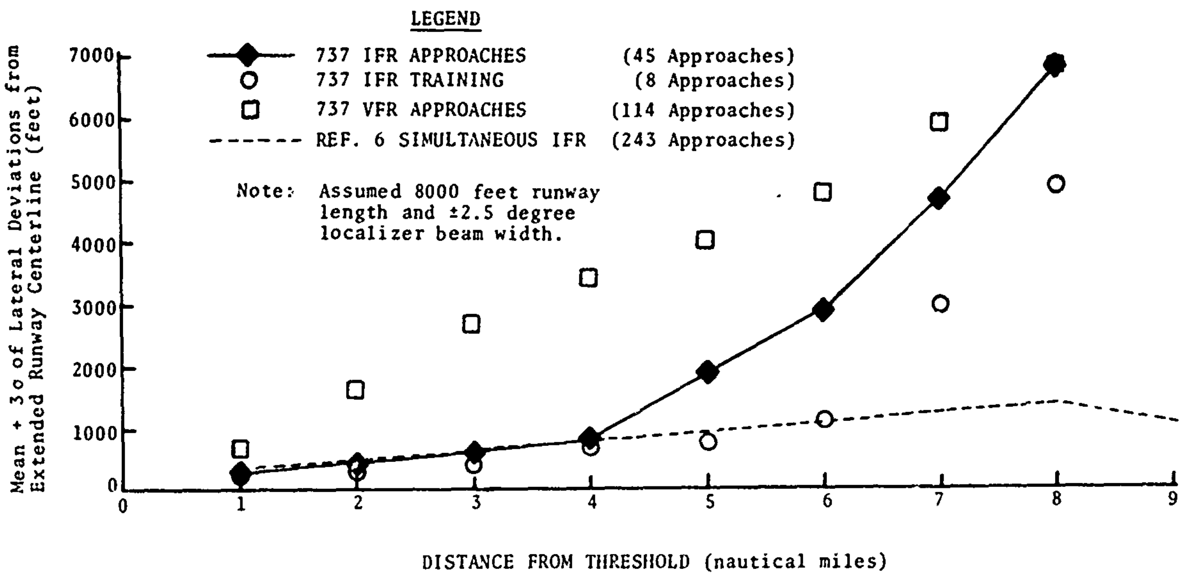
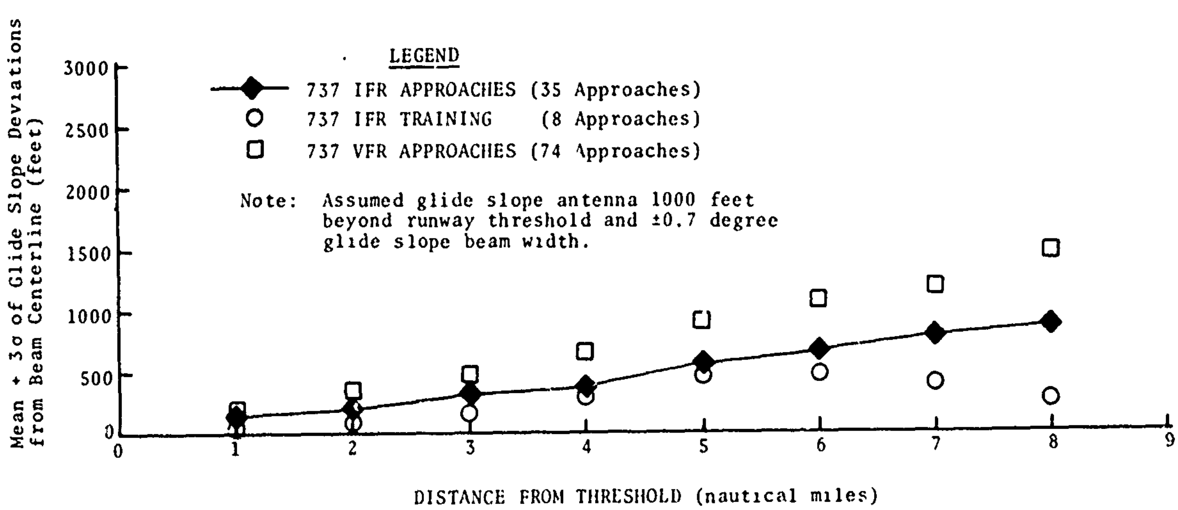


Figure 6. Localizer and Glide Slope Deviations During IFR Training Approaches



(a) Lateral Deviations (Localizer)



(b) Vertical Deviations (Glide Slope)

Figure 7. Summary of Recorded 737 ILS Data

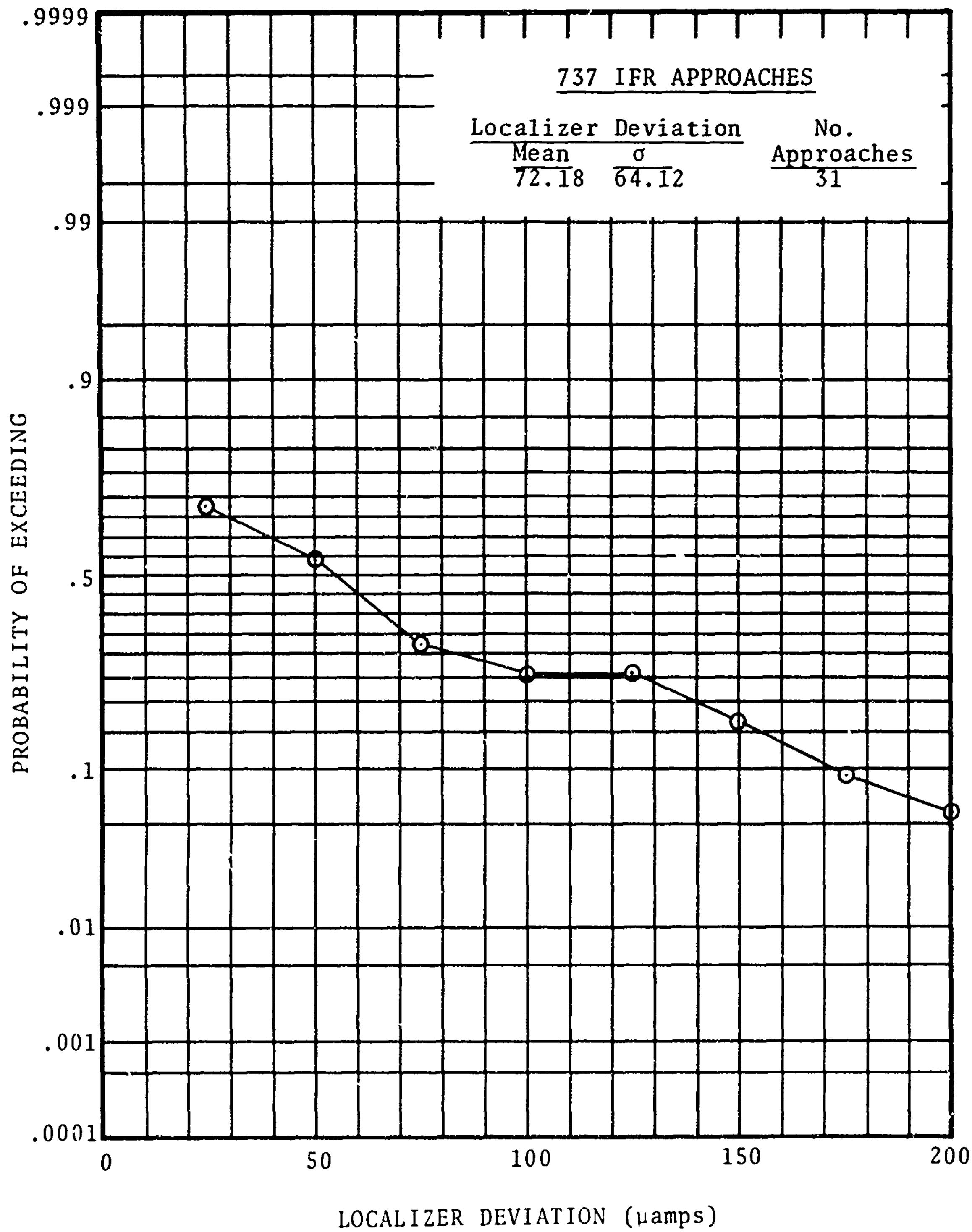


Figure 8. Probability of Exceeding a Localizer Deviation Level at Maximum Localizer Overshoot

TABLE 4. LOCALIZER DEVIATIONS DURING APPROACHES

(a) IFR Approaches

LOCALIZER DEVIATION
MICROAMPS

DIST TO THRESHLD	BELOW	-200	-175	-150	-125	-100	-75	-50	-25	0	25	50	75	100	125	150	175	200	TOTAL	MEAN	SIGMA
MAX LOC	1			3			5		7	3	4	2	2			2	1	1	31	5.96	96.36
50000 FT	7			4			1	3	2	7	2	2	1		2	1	1	6	39	1.00	141.00
48000 FT	5	1		2	1	1		3	1	10	2	3	1	1	1	1	2	3	38	.50	127.39
46000 FT	5	1		3	1		1	2	1	13	5	1	1	1		1	1	2	39	-14.28	115.93
44000 FT	4	2		3			2	4	4	9	6		1	1		1		2	39	-21.84	108.54
42000 FT	3		1	2	3		3	1	3	13	2	2	2		1			2	38	-16.47	100.27
40000 FT	2	1		2	1		4	2	4	12	5		2	1	2		1		39	-7.12	87.78
38000 FT	2				2	1	2	3	5	13	7	1	1	1	1		1		40	-1.75	75.43
36000 FT	1		1			1	2	2	9	12	9			1		3			4.	7.60	69.03
34000 FT	1			1		1	2	2	5	16	8	3	1	1		2			43	10.51	63.12
32000 FT	1				2			3	9	13	7	4	2	1		1			43	9.76	58.64
O MARK	1				1			1	7	23	7	2			1				43	6.58	46.88
30000 FT	1				1		1	1	10	19	5	2	2			1			43	8.30	52.12
28000 FT		1			1			1	10	22	3	4		1					43	5.23	42.97
26000 FT					2			1	9	26	4	1							43	2.81	29.89
24000 FT					1		1		15	20	5	1							43	2.76	24.79
22000 FT						1		2	12	22	5	1							43	3.06	24.42
20000 FT							1	1	11	22	6	2							43	8.04	24.45
18000 FT								1	11	25	4	3							44	11.95	20.46
16000 FT									8	24	10	2							44	14.22	17.74
14000 FT									11	26	7			1					45	14.20	21.66
12000 FT								1	6	33	3	1	1						45	11.57	17.77
10000 FT									10	34	1								45	8.28	10.39
8000 FT									8	29	7	1							45	12.04	14.65
6000 FT									7	31	5	2							45	13.42	16.95
4000 FT									8	31	5	1							45	12.00	13.48
M MARK									7	29	8	1							45	15.60	15.59
2000 FT								1	9	27	7							1	45	14.84	24.75
THRESHLD							2	1	3	33	3	2						1	45	13.51	30.39
TOUCHDN					1		1	1	2	33	4				1				44	8.00	35.42

(b) VFR Approaches

LOCALIZER DEVIATION
MICROAMPS

DIST TO THRESHLD	BELOW	-200	-175	-150	-125	-100	-75	-50	-25	0	25	50	75	100	125	150	175	200	TOTAL	MEAN	SIGMA
MAX LOC	1			2	2	2	2	3	15	7				1	1	2		3	41	-.04	92.25
50000 FT	15	1	2	2	2		1	5	13	20	4	7		2	2	4		14	94	2.55	130.63
48000 FT	16	1	1	2		2		3	13	19	9	6	1	2	1	5	1	13	95	6.10	129.96
46000 FT	12	3	1	2	1		1	5	9	20	10	5	2	3	2	7		12	95	11.30	126.11
44000 FT	14	2	1	2	1		2	5	9	21	8	6	4	3		5	2	13	98	9.90	127.58
42000 FT	12	2	4	2		1	1	1	13	20	11	4	5	2	1	4	1	14	98	11.88	126.97
40000 FT	12	1	3	2	1		1	3	14	20	12		5	5		2	4	13	98	14.57	124.80
38000 FT	11	2	1	4			1	8	11	21	11	1	8	1		5	2	13	100	13.22	121.11
36000 FT	10	2		2	3		2	6	13	22	9	8	2	2	1	5	1	12	100	14.68	115.65
34000 FT	9	2	2	2		1	5	5	10	23	11	6	6	2	1	3	4	10	102	14.67	113.96
32000 FT	9	4		2		2	1	4	11	28	15	2	3	2	1	7	1	11	103	16.57	113.66
O MARK	13	3		1		2	1	7	11	26	15	6	1	2	2	7		9	106	6.15	113.93
30000 FT	11	2		1	1	1	2	4	8	38	9	4	2	2	2	5	1	11	104	14.68	112.35
28000 FT	12	2		1	2	1	1	2	8	39	12	5	2		2	5	1	10	105	10.50	111.33
26000 FT	12	4		2	1		1	3	13	30	13	7		1	2	6	1	10	106	8.04	114.94
24000 FT	13	4		1		1	1	4	15	26	14	4	4	1	1	7	2	8	106	5.38	115.18
22000 FT	14		2	1	1			7	14	24	19	3	2		5	6	1	7	106	5.13	111.55
20000 FT	13	1	2	1		1		4	12	36	13	1	6	1		8		8	107	6.49	110.01
18000 FT	15	1			1		1	4	9	35	15	5	3	2	1	7	1	7	107	7.83	111.12
16000 FT	12	3	1		1		1	4	8	37	16	5	4	1	1	7	1	6	108	5.90	106.17
14000 FT	5	2	5	2		2	3	3	12	39	14	5	2		2	7	1	5	109	8.93	95.52
12000 FT	3	2		1	3	2	5	2	14	41	16	6	3	1		6		6	111	14.88	81.38
10000 FT	3					1	6	3	21	43	18	3	3	1	1	3	1	4	113	20.78	69.60
8000 FT	2	1			1	2	1	2	17	53	20	5	1	1	1	5		2	113	16.15	58.96
6000 FT				2	2	1	1		16	62	18	4	1			3		2	112	15.60	47.74
4000 FT		1	2	1					11	74	16	4				3		2	114	15.28	50.80
M MARK	3			1					12	76	14	2		1		3		2	114	13.64	53.84
2000 FT	3			1				1	8	74	18		3			4		2	114	17.39	56.17
THRESHLD	4	1		4		1	4	3	10	69	14	3		1					114	-4.07	57.18
TOUCHDN	3	1		4	3	3	2	4	10	71	12	1							114	-7.[illegible]	36.18

TABLE 4 - Concluded

(c) IFR Training Approaches

LOCALIZER DEVIATION
MICROAMPS

DIST TO THRESHLD	BELOW	-200	-175	-150	-125	-100	-75	-50	-25	0	25	50	75	100	125	150	175	200	TOTAL	MEAN	SIGMA
MAX LOC								1	1										2	-30.00	14.14
50000 FT									4		2							2	8	53.37	94.18
48000 FT									4	1	1							2	8	50.37	94.88
46000 FT									5		1					1		1	8	43.37	88.68
44000 FT									5		1		1					1	8	34.00	75.07
42000 FT									3	3	1						1		8	25.37	65.24
40000 FT									3	3	1			1					8	19.50	40.52
38000 FT									3	3	2								8	9.87	21.93
36000 FT								1	4	1	2								8	4.75	25.60
34000 FT								1	4	2	1								8	.12	23.16
32000 FT									5	2	1								8	1.75	18.47
O MARK									4	2	2								8	6.87	21.93
30000 FT									3	5									8	.75	12.44
28000 FT									3	5									8	4.62	14.29
26000 FT									4	2	2								8	9.00	20.45
24000 FT									4	3	1								8	6.50	20.99
22000 FT									4	4									8	-.75	14.75
20000 FT									4	4									8	-3.75	15.13
18000 FT									4	4									8	-2.87	15.14
16000 FT								1	2	5									8	-.62	14.63
14000 FT								1	3	4									8	-4.12	17.11
12000 FT									5	2	1								8	3.12	15.12
10000 FT									4	3	1								8	2.37	17.43
8000 FT								1	2	5									8	5.00	17.67
6000 FT									2	5	1								8	5.62	16.60
4000 FT									2	5	1								8	7.12	17.23
M MARK									1	6	1								8	8.62	13.54
2000 FT									3	5									8	8.12	12.75
THRESHLD									1	3	4								8	17.12	15.74
TOUCHDN										3	1								4	18.75	5.67

TABLE 5. GLIDE SLOPE DEVIATIONS DURING APPROACHES

(a) IFR Approaches

GLIDE SLOPE DEVIATION
MICROAMPS

DIST TO THRESHLD	BELOW	-150	-175	-100	-75	-50	-25	0	25	50	75	100	125	150	TOTAL	MEAN	SIGMA
MAX LOC						1	3	3	1	4	1	2	1	9	25	85.52	68.91
50000 FT	1						3	3	1	1	1	1	6	13	30	101.23	79.25
48000 FT							4	1	2	1		3	5	13	29	109.58	63.04
46000 FT							3	4	1		1	5	4	12	30	106.76	63.82
44000 FT							3	4	1	1	2	3	5	11	30	101.93	64.04
42000 FT						1	3	3	2		1	8	2	10	30	96.90	65.39
40000 FT							5	2	3		2	5	5	8	30	92.70	63.88
38000 FT							7	4		1	4	6	1	8	31	79.83	65.60
36000 FT						2	6	3	2	5	3	2	2	7	32	68.15	65.86
34000 FT						2	8	3	5	4	2	3		7	34	56.88	65.75
32000 FT						4	7	4	7	2	2	1	2	5	34	47.50	65.32
O MARK				1	3	4	6	10	5	3	1	1			34	5.41	45.26
30000 FT					1	3	10	5	2	4	2	2	2	3	34	37.32	63.80
28000 FT					2	6	7	6	2	4	2	2	3		34	23.17	57.86
26000 FT				1	1	5	8	6	4	5	3	1			34	13.61	47.31
24000 F					4	5	6	9	4	2	2	2			34	8.14	49.26
22000 FT			1		4	6	7	7	4	2	1	2			34	-1.05	49.50
20000 FT			1	3	3	3	12	6	1	1	3	1			34	-5.44	53.28
18000 FT	1	1			3	5	9	7	4	1	2	1			34	-2.91	56.22
16000 FT	1	1			1	8	5	11	3	2	1	1			34	-3.94	55.22
14000 FT	1				2	6	10	6	5	3		2			35	.60	49.79
12000 FT				2	2	5	8	10	2	3		3			35	4.22	49.84
10000 FT				1	2	3	13	5	6	2	1	2			35	9.97	44.68
8000 FT				1	3	4	7	9	5	2	2	2			35	10.97	49.84
6000 FT			1		2	5	11	7	3	2	1	3			35	6.42	50.05
4000 FT	1	1		1	2	4	7	2	3	7	1	3	2	1	35	20.00	75.81
M MARK		1		2	2	4	5		9	3	4	2		3	35	27.51	73.76
2000 FT	1	1	2	1	4	1	3	2	2	1	2	7	4	4	35	39.14	96.59
THRESHLD	5	2			1		2	1		1	2	3	2	16	35	62.68	123.62
TOUCHDN	2	2	1	2	3		2		1		3	1	2	15	34	56.64	119.19

TABLE 5 - Concluded

(b) VFR Approaches

GLIDE SLOPE DEVIATION MICROAMPS

DIST TO THRESHLD	BELOW	-150	-125	-100	-75	-50	-25	0	25	50	75	100	125	150	TOTAL	MEAN	SIGMA
MAX LOC	2	4	1		1		3	1	5	1	1	1		5	25	4.20	112.43
50000 FT	6	6	4	1	1	3	5	3	5		5	3	4	11	57	12.10	115.71
48000 FT	6	5	2	3	1	5	4	6	2	1	5	3	5	10	58	11.63	112.40
46000 FT	5	5	2	2	4	2	3	5	5	5	5	2	3	10	58	14.74	107.21
44000 FT	6	5	3	3	1	4	5	1	7	5	5	5	1	10	61	13.37	107.61
42000 FT	5	4	1	6	5	3	2	2	5	7	8	2	4	7	61	12.55	103.45
40000 FT	4	6	2	4	3	4	2	4	6	4	8	2	4	8	61	13.49	105.01
38000 FT	5	7	2		2	5	3	4	8	4	8	3	2	9	62	15.32	104.16
36000 FT	7	6	2	1		7	4	6	7	1	9	3	3	6	62	4.58	104.40
34000 FT	9	5	2		2	5	8	7	5	1	7	3	4	5	63	-3.25	102.94
[illegible]000 FT	11	3	2		2	6	6	9	7	1	7	5	1	3	63	-10.47	98.05
O MARK	11	3	1	6	2	4	4	7	11	3	8	2	1	3	66	-14.53	95.41
30000 FT	10	6	1	2	4	4	5	7	8	2	6	3	3	3	64	-13.82	100.25
28000 FT	10	6	1	3	3	5	8	6	10	1	6	3	1	2	65	-22.10	93.62
26000 FT	10	4		7	2	4	10	4	12	2	5	2	2	2	66	-19.57	91.59
24000 FT	10	5		4	4	3	9	8	10	3	5	1	1	3	66	-19.63	91.70
22000 FT	8	5	2	1	3	4	11	5	12	4	4	3		4	66	-11.03	90.89
20000 FT	9	4	1	4	4	5	6	5	12	5	7	3		3	66	-13.07	90.63
18000 FT	7	7	2	4	4	6	8	5	10	6	6	1		2	68	-22.26	86.63
16000 FT	5	7	3	3	4	8	8	8	9	2	6	2		3	68	-18.30	85.59
14000 FT	6	4	1	6	4	10	7	8	8	4	5	3		3	69	-13.30	83.79
12000 FT	4	2	3	3	3	10	9	10	10	5	5	2	2	3	71	.05	78.51
10000 FT	3	3	1	6	5	9	6	9	6	8	10	1	2	4	73	6.17	81.48
8000 FT	3	1		6	5	10	11	7	7	5	6	5	2	5	73	11.95	78.92
6000 FT	1	2		2	4	8	14	6	12	3	9	3	5	4	73	24.49	72.84
4000 FT	1	1		3	1	3	8	7	9	13	6	7	4	11	74	53.54	74.31
M MARK	1	1		1	2	4	10	11	8	4	11	6	5	10	74	49.98	72.50
2000 FT	1	1		2		1	6	4	10	8	8	9	4	20	74	76.08	74.26
THRESHLD	3	1	1	2	1	2	2	4	7	4	5	1	3	38	74	85.83	94.19
TOUCHDN	4	2	4	3		3	6	3	6	5	7	3	2	26	74	53.94	104.14

(c) IFR Training Approaches

GLIDE SLOPE DEVIATION MICROAMPS

DIST TO THRESHLD	BELOW	-150	-125	-100	-75	-50	-25	0	25	50	75	100	125	150	TOTAL	MEAN	SIGMA
MAX LOC												2			2	113.00	.00
50000 FT												1	2	5	8	145.87	16.70
48000 FT												3	1	4	8	140.00	19.14
46000 FT												2	2	4	8	143.37	17.35
44000 FT												1	4	3	8	142.87	14.96
42000 FT												3	2	3	8	136.25	19.97
40000 FT											1	2	2	3	8	131.87	24.38
38000 FT										1	1	2	1	3	8	121.87	34.23
36000 FT									1	1		3	2	1	8	110.37	36.66
34000 FT								1		1	1	4		1	8	96.00	44.67
32000 FT								1	1	2		1	3		8	81.37	50.41
O MARK					2	2	2	2							8	-23.50	33.51
30000 FT							1	[illegible]	1		1	3			8	55.50	49.98
28000 FT					1		2		1	2	2				8	27.75	53.57
26000 FT				1	1		1	2	3						8	-2.50	46.26
24000 FT				1	1	1	3	1	1						8	-18.12	37.57
22000 FT				1	2	1	4								8	-39.87	31.43
20000 FT				1	2	3	2								8	-48.87	27.52
18000 FT				1	2	3	1	1							8	-41.25	29.68
16000 FT					1	4	3								8	-34.25	19.55
14000 FT					1	3	4								8	-25.87	20.98
12000 FT					2	4	2								8	-30.75	20.51
10000 FT				1		2	5								8	-21.87	25.27
8000 FT				1		1	3	3							8	-15.50	31.61
6000 FT						3	5								8	-24.62	12.11
4000 FT						1	6	1							8	-14.00	14.46
M MARK					3	4	1								8	-47.87	15.00
2000 FT				1	2	3	1		1						8	-36.62	36.19
THRESHLD	5		2											1	8	-108.50	109.18
TOUCHDN						3							1		4	7.75	86.85

TABLE 6. BANK ANGLES DURING APPROACHES

(a) IFR Approaches

BANK ANGLE DEGREES

DIST TO THRESHLD	BELOW	-20	-15	-10	-5	0	5	10	15	20	TOTAL	MEAN	SIGMA
MAX LOC	4	1		1	1	8	1	4	1	5	26	3.30	17.57
50000 FT	6	2	2		5	11	1	1	3	3	34	-1.29	15.47
48000 FT	5	1	1	1	4	15	2	1	1	2	33	-1.51	13.33
46000 FT	2	2		1	10	20	2	2	2	3	34	.50	12.79
44000 FT	2	1	1	3	6	11	3	3	1	3	34	1.50	12.58
42000 FT	2			4	5	15	3		3	1	33	.63	10.45
40000 FT	2			2	3	15	5	[illegible]		2	34	2.76	9.62
38000 FT	1		1	4	3	13	6	[illegible]	2	2	34	1.82	13.90
36000 FT	1			2	2	18	5	[illegible]	2	2	35	3.88	9.25
34000 FT				2	2	16	12	2		2	36	5.22	7.14
32000 FT				3	4	16	10	2		1	36	3.25	6.62
O MARK			1	2	4	22	5	1	1		36	1.44	5.30
30000 FT			1	3	2	18	11	1			36	2.00	4.93
28000 FT			1	4	4	22	4		1		36	.91	5.12
26000 FT				2	6	21	5	1	1		36	2.27	4.78
24000 FT				1	4	24	5	1	1		36	1.88	4.45
22000 FT			1		7	23	4		1		36	1.44	4.64
20000 FT				2	7	21	5		1		36	2.02	4.15
18000 FT				1	2	26	5	2	1		37	2.89	4.35
16000 FT					5	27	5				37	2.32	2.66
14000 FT					6	24	6	1	1		38	2.65	4.01
12000 FT				1	7	23	6	1			38	2.02	3.84
10000 FT				1	8	27	2				38	.94	3.05
8000 FT			1	1	4	26	5	1			38	1.84	4.29
6000 FT					5	26	6		1		38	2.18	3.68
4000 FT			1		5	28	4				38	1.13	3.33
M MARK					6	27	4	1			38	1.44	2.94
2000 FT	1				6	29	2				38	.34	4.58
THRESHLD	1				3	32	1	1			38	.89	5.11
TOUCHDN					2	33	2				37	1.21	1.93

(b) VFR Approaches

BANK ANGLE DEGREES

DIST TO THRESHLD	BELOW	-20	-15	-10	-5	0	5	10	15	20	TOTAL	MEAN	SIGMA
MAX LOC	3	2	3	7	4	10		2	5	2	38	-1.31	13.75
50000 FT		1	1	3	12	51	6	4	3	3	84	2.30	7.07
48000 FT	1		1	5	7	57	5		2	7	85	2.60	8.06
46000 FT	1		1	2	11	58	5		3	4	85	2.38	7.22
44000 FT			1	4	10	56	9	3		4	87	2.51	6.26
42000 FT		1	1	3	8	67	2	3		2	87	1.64	5.61
40000 FT		1		6	12	57	7	2		2	87	1.37	5.80
38000 FT	1		2		16	58	5	2	1	4	89	1.69	6.89
36000 FT	3	1		5	9	62	4	1	2	2	89	.65	7.48
34000 FT	3	1		6	13	60	5	2		1	91	.13	6.88
32000 FT	3			7	13	56	6	5		1	91	.60	6.56
O MARK	4	1	2	2	17	54	8	3	2	1	94	.22	7.62
30000 FT	1	5	2	5	11	56	6	6			92	-.15	7.03
28000 FT	3	1	5	4	14	53	9	1	3		93	-.18	7.06
26000 FT	1	3	2	4	12	57	6	6	3		94	.55	7.09
24000 FT	2		4	6	13	55	6	4	1	3	94	.68	7.53
22000 FT	2	2	2	3	13	54	9	2	5	2	94	1.20	7.78
20000 FT	2	3	1	6	10	52	10	3	5	[illegible]	96	1.83	8.76
18000 FT	2	2	5	3	11	57	7	3	3	3	96	1.31	8.22
16000 FT	2	3	2	3	11	62	7	2	1	3	96	.56	8.14
14000 FT	2	3	2	4	10	61	9	2	2	1	96	.56	7.47
12000 FT		2	4	4	13	64	7	1	2	1	98	.73	5.95
10000 FT	1			2	12	73	8	1	1	2	100	1.57	5.54
8000 FT	1	1	2	2	11	72	7	2	1	1	100	1.10	5.41
6000 FT				3	9	81	5			1	99	1.24	3.29
4000 FT					11	81	9				101	1.39	2.24
M MARK					15	84	2				101	1.00	1.94
2000 FT					13	86	2				101	.91	1.86
THRESHLD					10	90	1				101	.98	1.67
TOUCHDN					11	89	1				101	.72	1.49

TABLE 6 - Concluded

(c) IFR Training Approaches

DIST TO THRESHLD	BELOW	-20	-15	-10	-5	0	5	10	15	20	TOTAL	MEAN	SIGMA
								BANK ANGLE DEGREES					
MAX LOC	1		1								2	-17.00	7.07
50000 FT	1	1	1	1		3	1				8	-7.12	10.45
48000 FT	3					4	1				8	-7.00	12.83
46000 FT	1	1	1		1	3	1				8	-5.25	10.55
44000 FT	1		1		3	2	1				8	-5.00	11.04
42000 FT	1				2	5					8	-3.50	10.51
40000 FT				1		6	1				8	.87	3.60
38000 FT	1				2	3	1		1		8	-1.12	13.85
36000 FT			1		2	3		2			8	1.12	8.54
34000 FT				1	1	5	1				8	-.12	4.70
32000 FT				1	1	6					8	-.87	4.18
O MARK						7		1			8	2.12	3.56
30000 FT					1	7					8	1.50	2.32
28000 FT				1		7					8	.37	3.42
26000 FT					1	5	1	1			8	2.25	4.30
24000 FT						7		1			8	2.12	3.56
22000 FT					1	7					8	.87	1.95
20000 FT				1	2	5					8	-.50	3.66
18000 FT					2	6					8	.50	2.32
16000 FT					2	5	1				8	.87	2.94
14000 FT					2	5	1				8	1.12	3.04
12000 FT					1	6	1				8	1.50	2.97
10000 FT						8					8	1.00	1.41
8000 FT					1	7					8	1.12	2.41
6000 FT					1	7					8	.87	2.29
4000 FT				1	1	6					8	-.25	3.15
M MARK					2	6					8	.87	3.22
2000 FT					2	6					8	1.50	2.56
THRESHLD						5	3				8	3.12	3.13
TOUCHDN						4					4	1.75	1.25

TABLE 7. INDICATED AIRSPEEDS DURING APPROACHES

(a) IFR Approaches

DIST TO THRESHLD	BELOW	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240	250	TOTAL	MEAN	SIGMA
											AIR SPEED KNOTS										
MAX LOC				1	1	3	10	4	3	2	2	1	1		1	1		1	31	162.09	31.10
50000 FT						7	11	7	5		3	2		3			1		39	160.51	27.54
48000 FT						9	9	7	4	1	3	1	3				1		38	158.23	25.76
46000 FT						6	15	6	3		3	4	1				1		39	157.94	24.25
44000 FT					1	7	14	7	1	3	1	4				1			39	154.92	21.98
42000 FT				1		11	11	6		3	5				1				38	152.21	20.84
40000 FT				1		14	11	5		5	2			1					39	149.15	18.32
38000 FT				1	4	14	9	4	3	2	2		1						40	145.27	18.27
36000 FT				2	3	15	13	2	2	2	1	1							41	142.53	16.13
34000 FT				3	5	17	10	3	2	2	1								43	140.62	15.19
32000 FT				2	7	17	9	2	4	1	1								43	139.55	14.88
O MARK				2	10	18	6	4	3										43	135.74	12.45
30000 FT				2	11	17	6	3	3		1								43	137.34	14.34
28000 FT				2	14	16	6	1	3		1								43	135.53	14.48
26000 FT				3	15	17	3	1	3		1								43	133.58	13.94
24000 FT				5	17	14	2	3	1	1									43	131.48	13.00
22000 FT				4	21	11	3	3	1										43	130.39	11.55
20000 FT				5	20	9	6	3											43	129.20	10.08
18000 FT				7	22	10	4	1											44	127.38	9.59
16000 FT			1	9	19	14		1											44	126.36	9.10
14000 FT				12	20	12	1												45	124.73	7.98
12000 FT				12	23	10													45	123.68	6.92
10000 FT				12	23	10													45	123.44	6.87
8000 FT			1	17	19	8													45	122.40	6.47
6000 FT			3	17	21	4													45	120.97	6.93
4000 FT			2	21	18	4													45	120.15	6.90
M MARK			1	24	15	5													45	120.22	6.52
2000 FT			1	21	21	2													45	120.24	5.72
THRESHLD			3	23	17	2													45	118.48	5.99
TOUCHDN			8	23	13														44	114.95	6.09

TABLE 7 - Concluded

(b) VFR Approaches

AIR SPEED KNOTS

DIST TO THRESHLD	BELOW	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240	250	TOTAL	MEAN	SIGMA
MAX LOC						5		3	7	1	1	5	2	2	2	3	4	6	41	199.50	46.82
50000 FT				1		6	13	20	10	12	7	5	3	7	2	3	4	1	94	174.15	31.91
48000 FT				1		10	11	19	10	15	6	4	6	4	1	4	3	1	95	171.56	30.96
46000 FT				1		11	14	18	11	13	4	5	8	3		4	3		95	169.47	29.58
44000 FT				1	2	11	18	14	14	8	7	10	3	3	3	3	1		98	166.55	28.14
42000 FT				1	8	7	19	15	13	6	10	8	4	1	4	1	1		98	164.45	27.59
40000 FT			1	1	5	12	19	16	11	9	9	6	3	3	2		1		98	161.38	25.60
38000 FT				2	8	13	15	19	13	12	9	2	3	3		1			100	158.57	23.82
36000 FT				2	9	16	25	13	13	12	5	3	2	1		1			100	154.30	22.07
34000 FT				4	10	23	19	16	12	10	4	2	1		1				102	150.21	20.65
32000 FT			1	4	16	18	19	19	11	9	3	2			1				103	147.73	19.73
O MARK				5	25	24	26	12	7	6	1								106	140.77	15.54
30000 FT				4	20	19	24	15	12	7	2		1						104	144.75	17.85
28000 FT			1	6	19	26	24	12	11	4	1	1							105	141.64	16.27
26000 FT			1	8	25	27	17	17	8	2	1								106	138.96	15.00
24000 FT			1	9	25	32	21	15	1	2									106	136.28	13.30
22000 FT			3	7	28	36	18	12	1	1									106	134.53	12.65
20000 FT			2	7	35	34	20	7	1	1									107	132.90	11.50
18000 FT			3	13	33	34	19	3	1	1									107	131.14	11.48
16000 FT			2	21	34	35	11	4	1										108	129.12	10.94
14000 FT			3	26	40	23	14	2	1										109	127.31	11.07
12000 FT			2	31	42	24	9	2	1										111	125.79	10.69
10000 FT			3	35	44	23	5	2	1										113	124.53	10.21
8000 FT			4	37	48	18	4	2											113	123.49	9.77
6000 FT			4	38	47	19	2	2											112	122.70	9.10
4000 FT			6	44	46	15	3												114	121.35	8.56
M MARK			5	44	49	13	3												114	121.41	7.39
2000 FT			4	49	48	11	2												114	120.55	7.41
THRESHLD			8	64	34	8													114	117.90	6.65
TOUCHDN		3	31	58	19	3													114	113.63	7.70

(c) IFR Training Approaches

AIR SPEED KNOTS

DIST TO THRESHLD	BELOW	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240	250	TOTAL	MEAN	SIGMA
MAX LOC						1	1												2	142.00	8.48
50000 FT						3	2	1	2										8	149.00	12.25
48000 FT						3	2		3										8	149.25	12.55
46000 FT						3	2		3										8	148.62	13.95
44000 FT						1	4		3										8	149.50	12.17
42000 FT						1	4		3										8	150.25	11.38
40000 FT						1	4	1	2										8	149.75	10.18
38000 FT						1	5	1	1										8	148.75	8.01
36000 FT						1	4	2	1										8	149.12	11.03
34000 FT						1	3	3	1										8	148.00	9.54
32000 FT					1		3	4											8	146.62	9.86
O MARK					2	2	3	1											8	140.12	9.14
30000 FT					1		4	2	1										8	145.87	10.00
28000 FT					1	2	3	1	1										8	144.00	9.87
26000 FT					1	2	4	1											8	141.12	9.17
24000 FT					1	3	3	1											8	140.37	8.81
22000 FT					3	2	3												8	135.37	11.74
20000 FT					4	1	3												8	133.25	11.39
18000 FT				1	3	2	2												8	130.87	10.76
16000 FT				3	1	2	1	1											8	131.00	13.03
14000 FT				4		3		1											8	128.12	14.01
12000 FT				3	1	3	1												8	126.12	10.61
10000 FT				3	2	2	1												8	127.37	12.36
8000 FT				3	1	3	1												8	125.75	10.79
6000 FT				2	2	4													8	126.00	9.50
4000 FT				3	2	3													8	124.00	9.78
M MARK				3	2	3													8	123.87	9.71
2000 FT				3	2	3													8	123.75	9.67
THRESHLD			1	2	1	4													8	125.25	11.29
TOUCHDN					1	3													4	129.00	2.00

TABLE 8. STALL MARGINS DURING APPROACHES

(a) IFR Approaches

STALL MARGIN

DIST TO THRESHLD	BELOW	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5	TOTAL	MEAN	SIGMA
MAX LOC					3	7	7	5	7		1								30	1.48	.15
50000 FT					6	5	7	12	2	4	1	1							38	1.50	.17
48000 FT					3	8	10	6	4	2	4								37	1.50	.17
46000 FT					3	7	12	7	5	2	2								38	1.49	.15
44000 FT					3	8	12	7	6	2									38	1.46	.13
42000 FT				1	4	7	12	6	7										37	1.44	.13
40000 FT					3	14	9	7	5										38	1.42	.11
38000 FT					8	12	9	7	3										39	1.40	.12
36000 FT					10	15	7	4	2	2									40	1.38	.13
34000 FT				3	9	13	9	4	4										42	1.38	.12
32000 FT				2	9	14	10	4	3										42	1.38	.12
O MARK				1	13	11	12	3	2										42	1.35	.10
30000 FT					12	11	12	4	3										42	1.38	.11
28000 FT					12	14	10	3	3										42	1.37	.11
26000 FT					12	16	9	2	3										42	1.36	.10
24000 FT				2	15	14	6	4	1										42	1.34	.10
22000 FT				2	13	16	6	4	1										42	1.34	.10
20000 FT				2	12	13	12	3											42	1.34	.10
18000 FT				2	13	18	8	2											43	1.33	.09
16000 FT				3	14	18	7	1											43	1.32	.09
14000 FT				4	15	15	9	1											44	1.31	.08
12000 FT				3	23	16	5												44	1.30	.07
10000 FT				4	19	13	8												44	1.30	.07
8000 FT				4	21	15	4												44	1.29	.07
6000 FT				9	17	16	2												44	1.27	.07
4000 FT			1	7	21	12	3												44	1.26	.07
M MARK				6	24	11	3												44	1.27	.07
2000 FT				6	23	14	1												44	1.26	.06
THRESHLD				8	28	7	1												44	1.24	.06
TOUCHDN				15	24	4													43	1.21	.05

(b) VFR Approaches

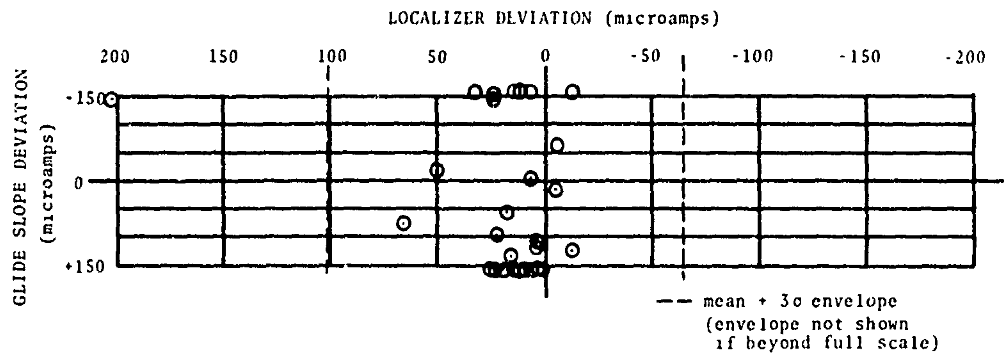
STALL MARGIN

DIST TO THRESHLD	BELOW	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5	TOTAL	MEAN	SIGMA
MAX LOC					1	3	2	10	8	6	5	4							41	1.68	.26
50000 FT				1		12	16	29	18	12	3	2							93	1.55	.14
48000 FT				1	1	13	18	30	18	9	2	2							94	1.53	.14
46000 FT					2	12	26	22	17	10	5								94	1.53	.15
44000 FT				1	4	12	27	19	20	10	4								97	1.52	.14
42000 FT				2	4	14	23	22	16	14	2								97	1.52	.15
40000 FT				1	7	14	28	21	17	7	2								97	1.50	.14
38000 FT				2	9	15	21	24	21	5	1								98	1.49	.14
36000 FT				2	6	20	28	22	15	5									98	1.47	.13
34000 FT				1	10	27	25	24	8	5									100	1.44	.13
32000 FT				2	14	25	26	19	11	6									101	1.43	.13
O MARK					15	41	25	16	6	1									104	1.40	.11
30000 FT				2	13	29	25	23	8	2									102	1.42	.12
28000 FT				1	15	32	28	18	7	2									103	1.41	.12
26000 FT				1	20	34	26	17	5	1									104	1.39	.11
24000 FT				3	22	33	34	10	1	1									104	1.37	.10
22000 FT				4	24	40	26	9		1									104	1.36	.10
20000 FT				2	23	46	24	9	1										105	1.35	.09
18000 FT			1	2	33	39	21	7	2										105	1.34	.09
16000 FT			1	1	36	44	17	6	1										106	1.33	.09
14000 FT				9	30	45	16	6	1										107	1.33	.09
12000 FT				8	39	37	19	4	2										109	1.31	.09
10000 FT				9	44	39	12	5	2										111	1.31	.09
8000 FT			1	9	46	39	12	3	1										111	1.30	.09
6000 FT			1	11	49	35	10	3	1										110	1.29	.08
4000 FT			1	12	55	33	9	2											112	1.28	.08
M MARK			1	11	56	37	6	1											112	1.28	.07
2000 FT			1	11	57	35	7	1											112	1.27	.07
THRESHLD			1	25	59	24	3												112	1.24	.06
TOUCHDN			5	31	43	13													112	1.20	[illegible]

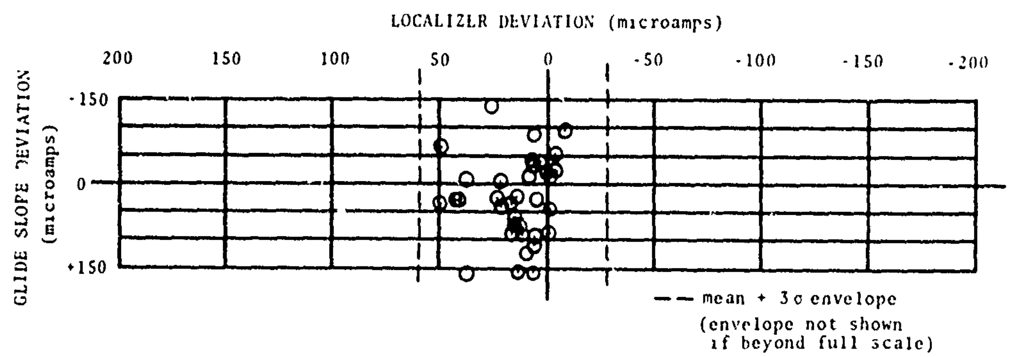
TABLE 8 - Concluded

(c) IFR Training Approaches

DIST TO THRESHLD	BELOW	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5	TOTAL	MEAN	SIGMA
	STALL MARGIN																				
MAX LOC							1			1									2	1.58	.18
50000 FT							3	1	3	1									8	1.59	.12
48000 FT							2	2	2	2									8	1.59	.11
46000 FT						1	1	2	2	2									8	1.58	.12
44000 FT							2	2	2	2									8	1.59	.11
42000 FT							1	3	2	2									8	1.60	.10
40000 FT							1	3	3	1									8	1.60	.09
38000 FT							1	3	3	1									8	1.60	.08
36000 FT						1		2	2	3									8	1.61	.12
34000 FT						1		1	3	3									8	1.60	.10
32000 FT						1		2	4	1									8	1.59	.12
O MARK						1	1	2	4										8	1.55	.10
30000 FT						1		2	4	1									8	1.58	.10
28000 FT						1	1	3	2	1									8	1.57	.10
26000 FT						1	2	1	4										8	1.54	.10
24000 FT							3	2	3										8	1.54	.10
22000 FT						1	2	3	2										8	1.53	.10
20000 FT							3	3	2										8	1.53	.07
18000 FT							4	3	1										8	1.50	.05
16000 FT						1	3	2	2										8	1.50	.08
14000 FT						3	1	3	1										8	1.47	.09
12000 FT						2	3	3											8	1.45	.06
10000 FT						3	2	2	1										8	1.46	.09
8000 FT						2	3	3											8	1.44	.07
6000 FT						2	4	1	1										8	1.45	.08
4000 FT						2	5	1											8	1.42	.06
M MARK						3	5												8	1.42	.05
2000 FT						2	6												8	1.42	.04
THRESHLD					1	2	3	2											8	1.42	.10
TOUCHDN						1	3												4	1.42	.03

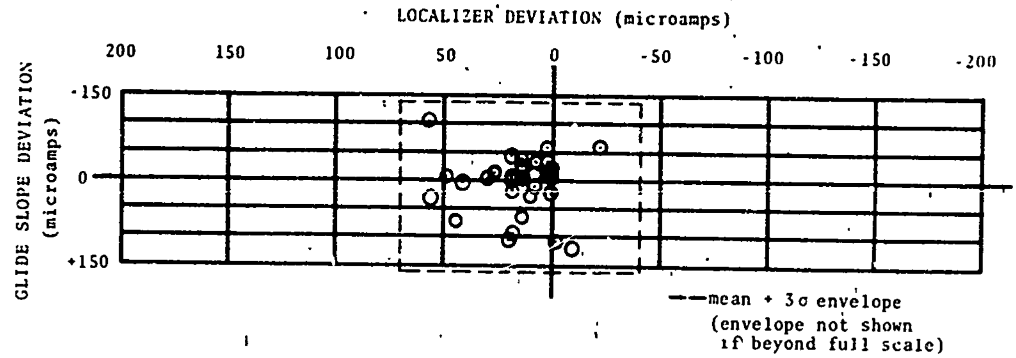


(a) Threshold

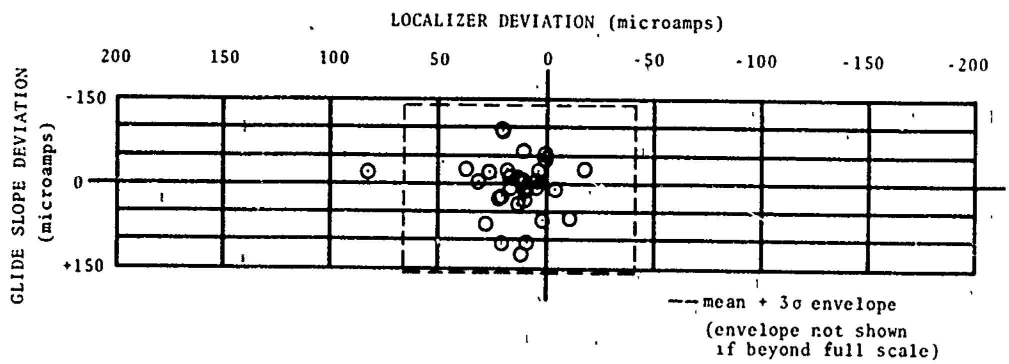


(b) Middle Marker

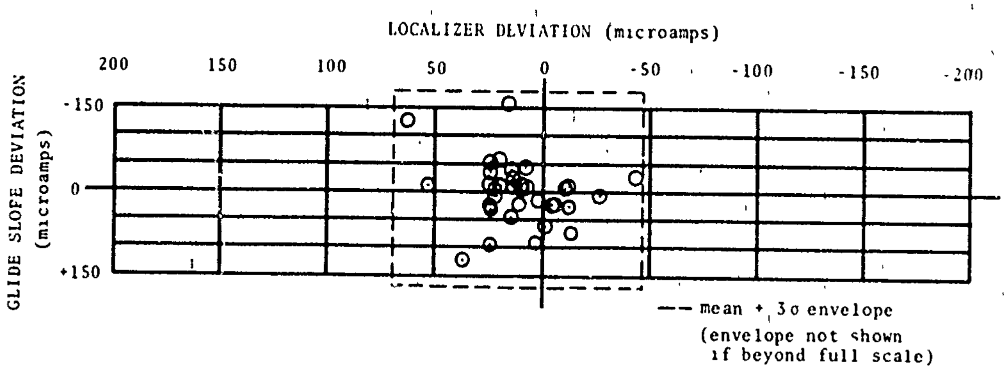
Figure 9. Localizer and Glide Slope Deviations at Eleven Approach Windows



(c) 6,000 Feet

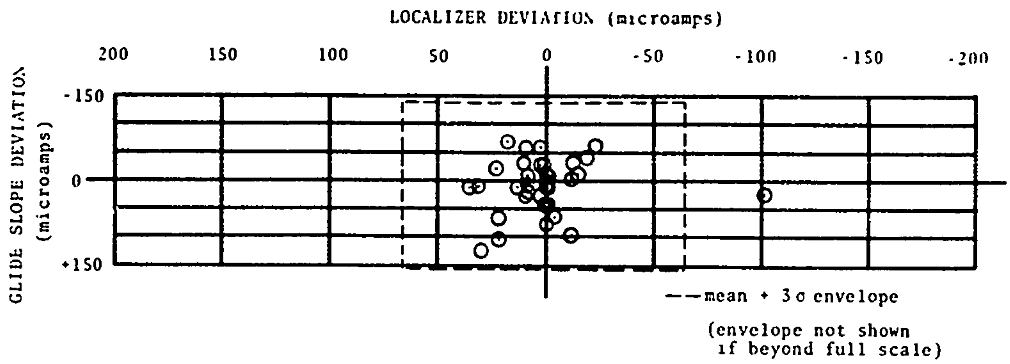


(d) 12,000 Feet

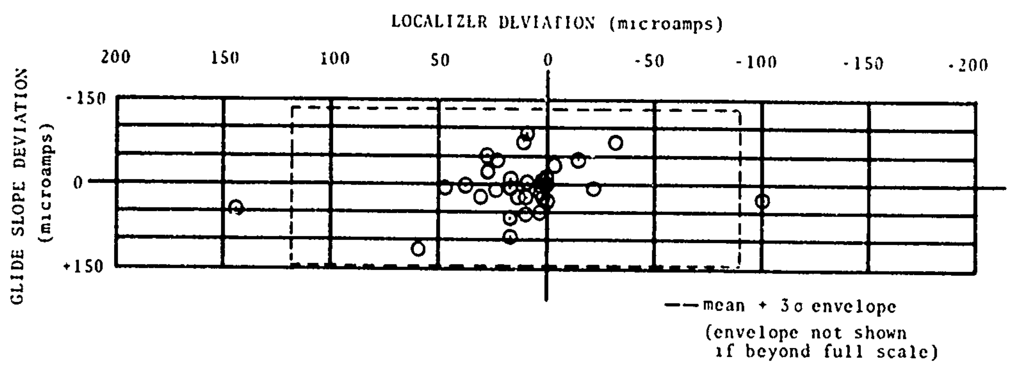


(e) 18,000 Feet

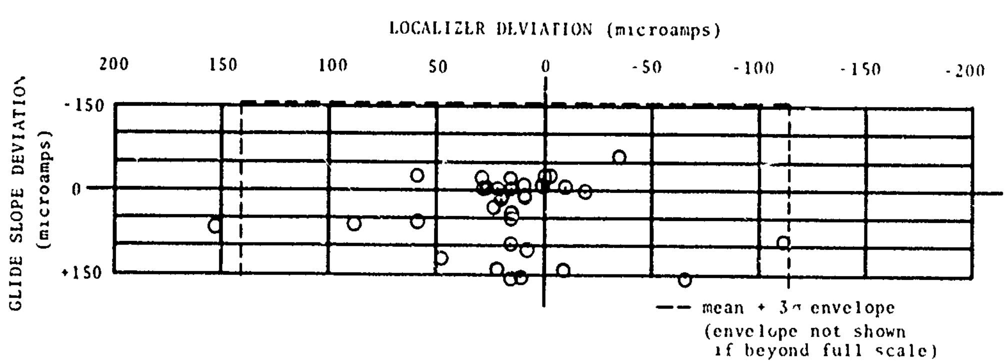
Figure 9 - Continued



(f) 24,000 Feet

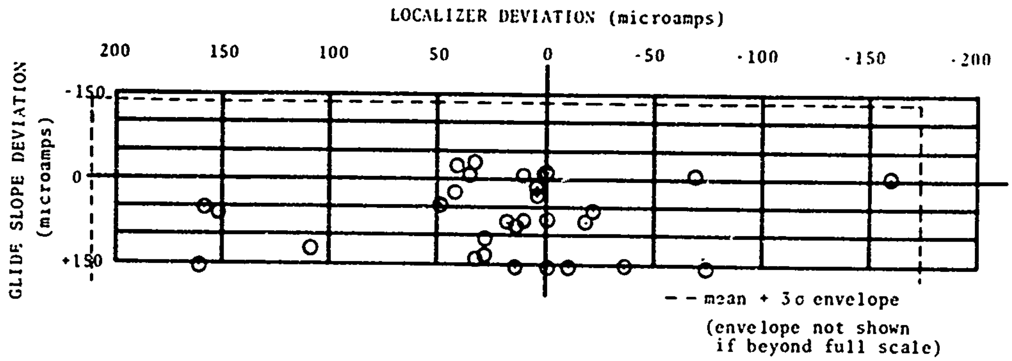


(g) Outer Marker

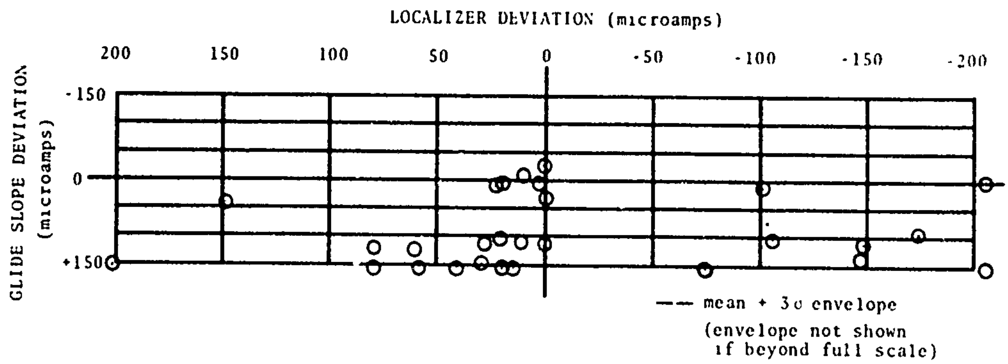


(h) 30,000 Feet

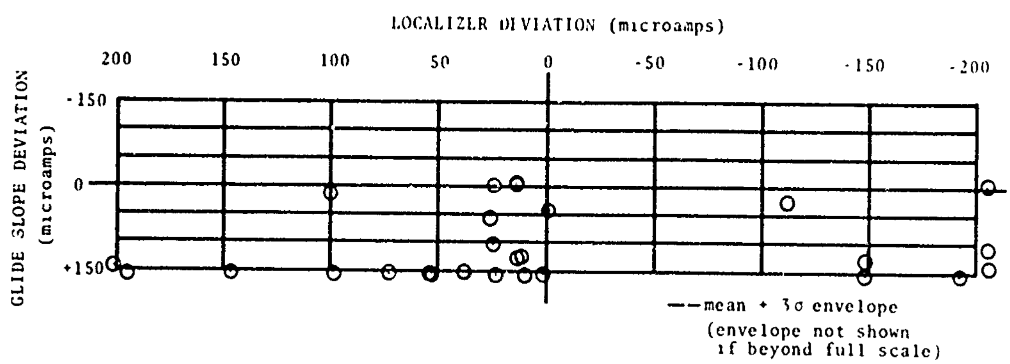
Figure 9 - Continued



(i) 36,000 Feet

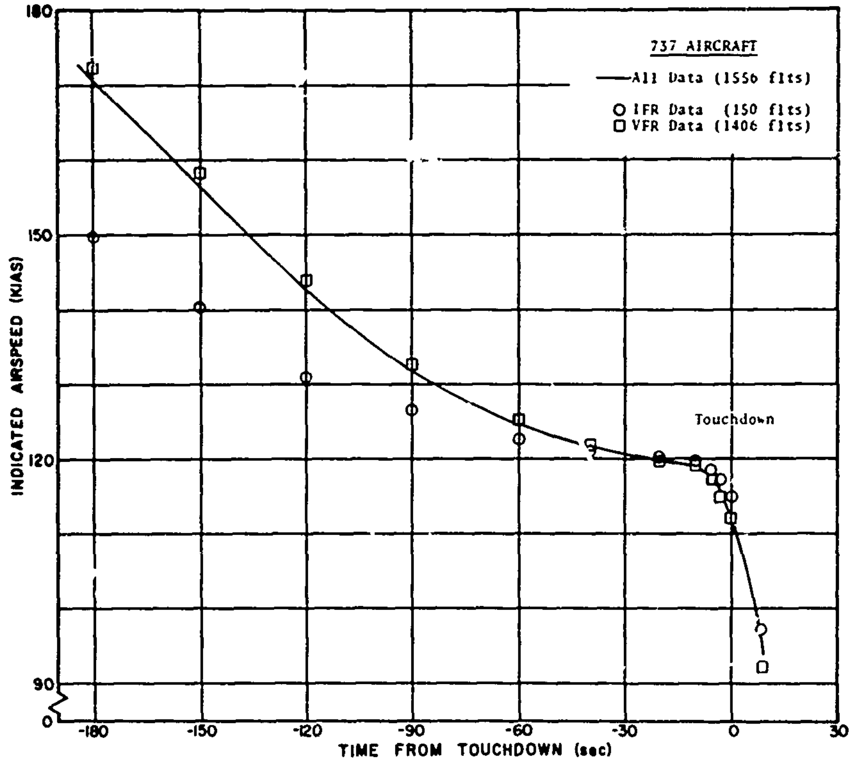


(j) 42,000 Feet

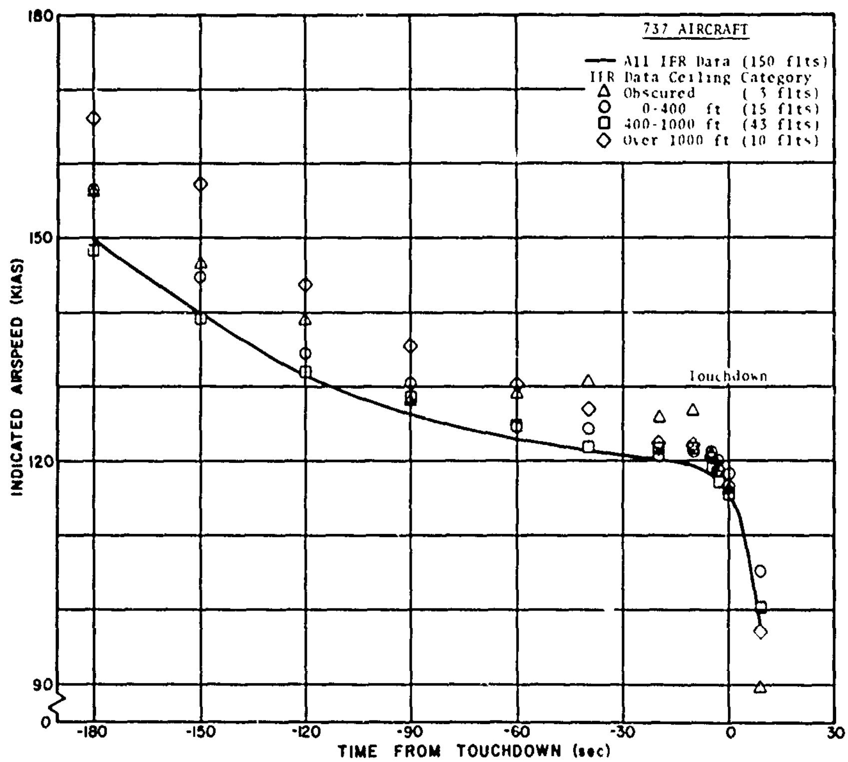


(k) 48,000 Feet

Figure 9 - Concluded

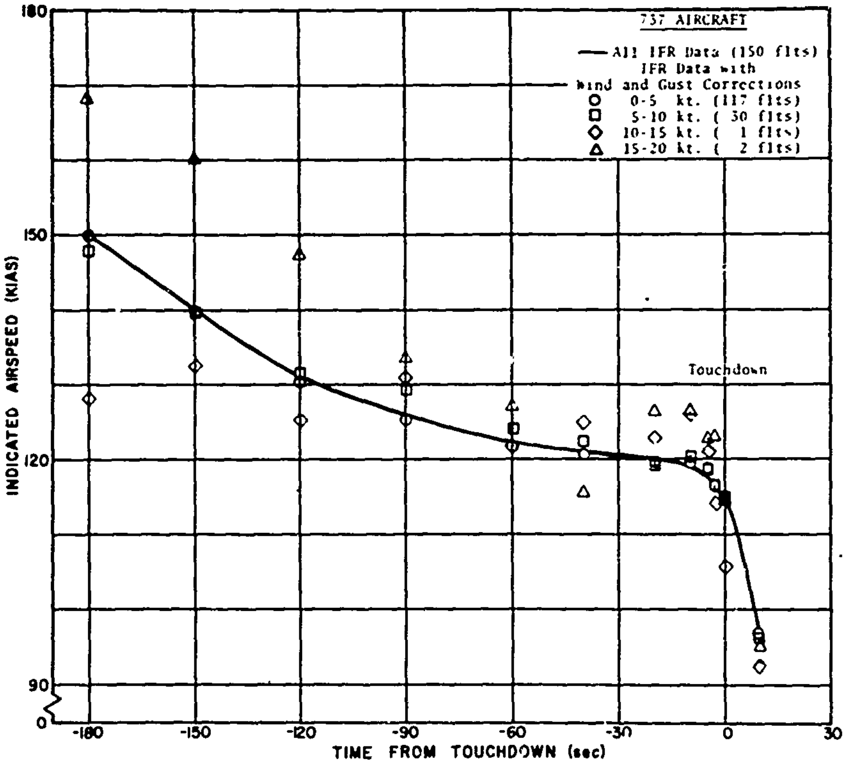


(a) Comparison of IFR to VFR Approaches

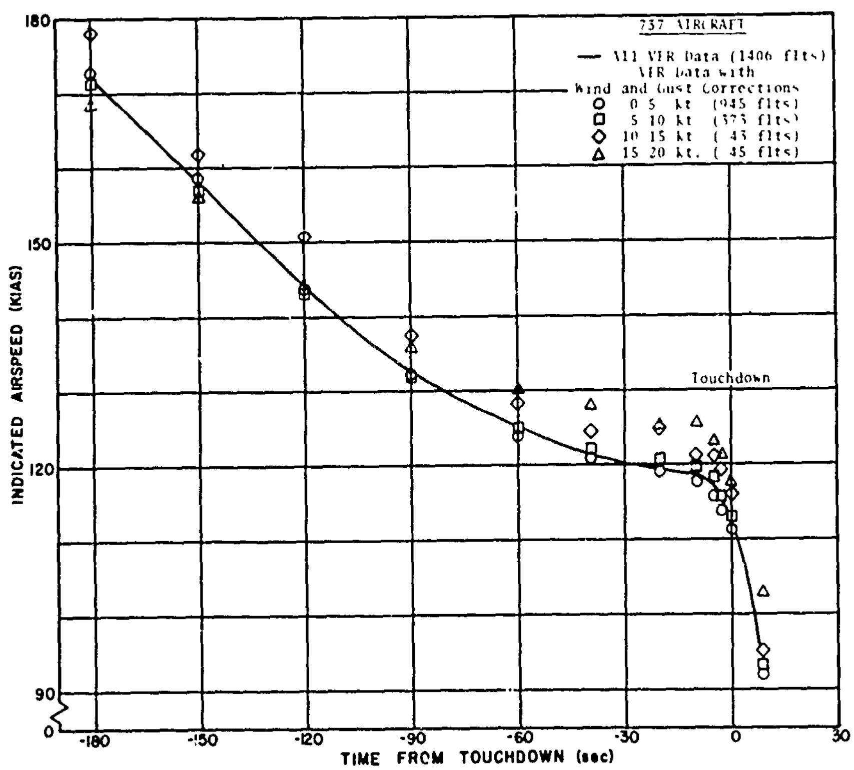


(b) Comparison of IFR Approaches by Ceiling

Figure 10. Time History of Mean Indicated Airspeed During IFR and VFR Approaches

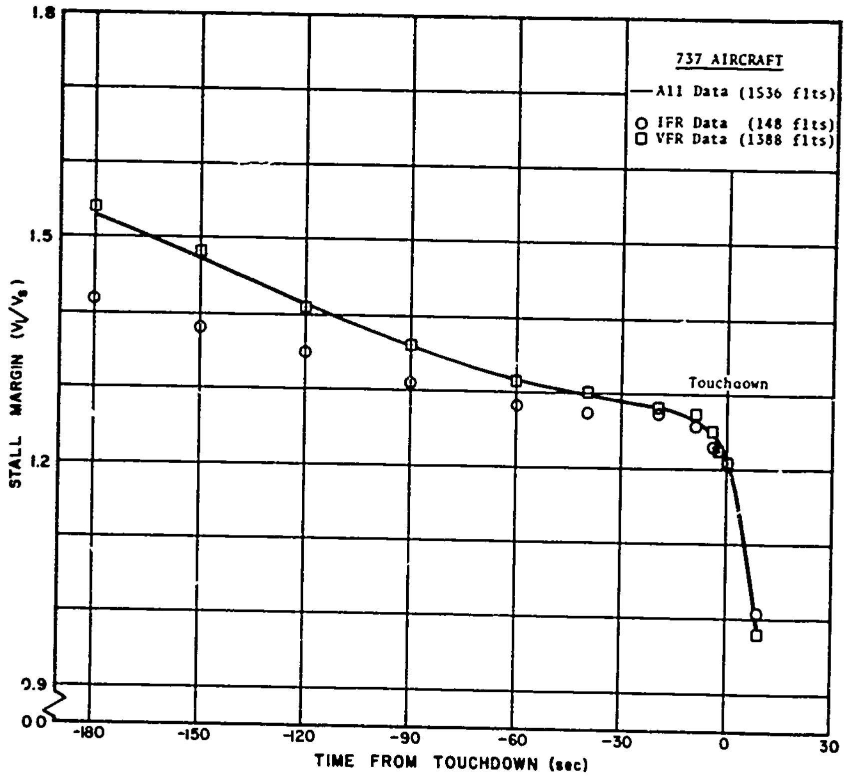


(c) Comparison of IFR Approaches by Wind Speed

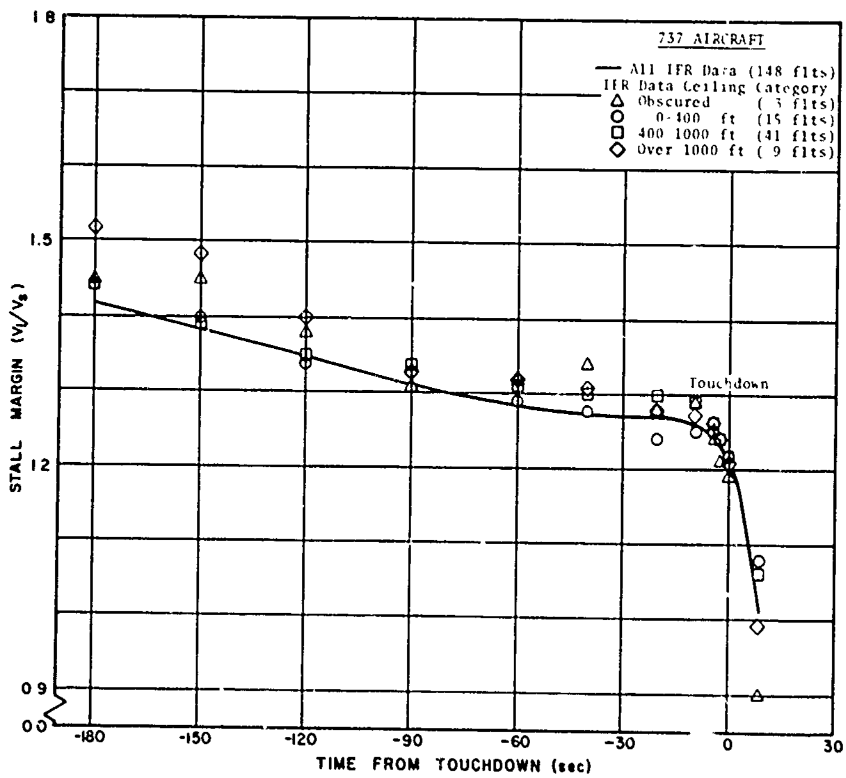


(d) Comparison of VFR Approaches by Wind Speed

Figure 10 - Concluded

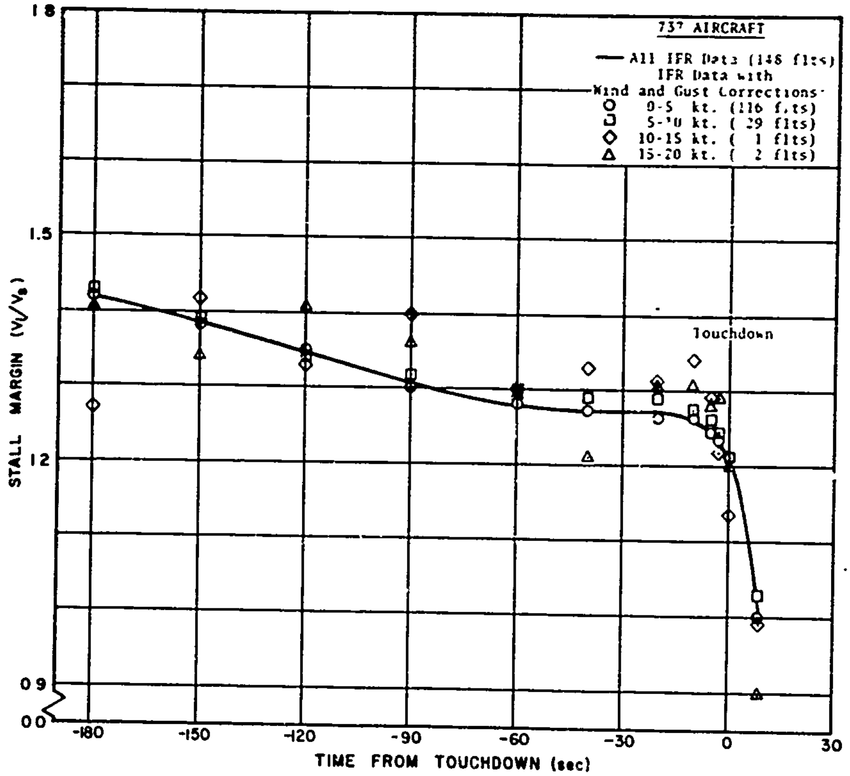


(a) Comparison of IFR to VFR Approaches

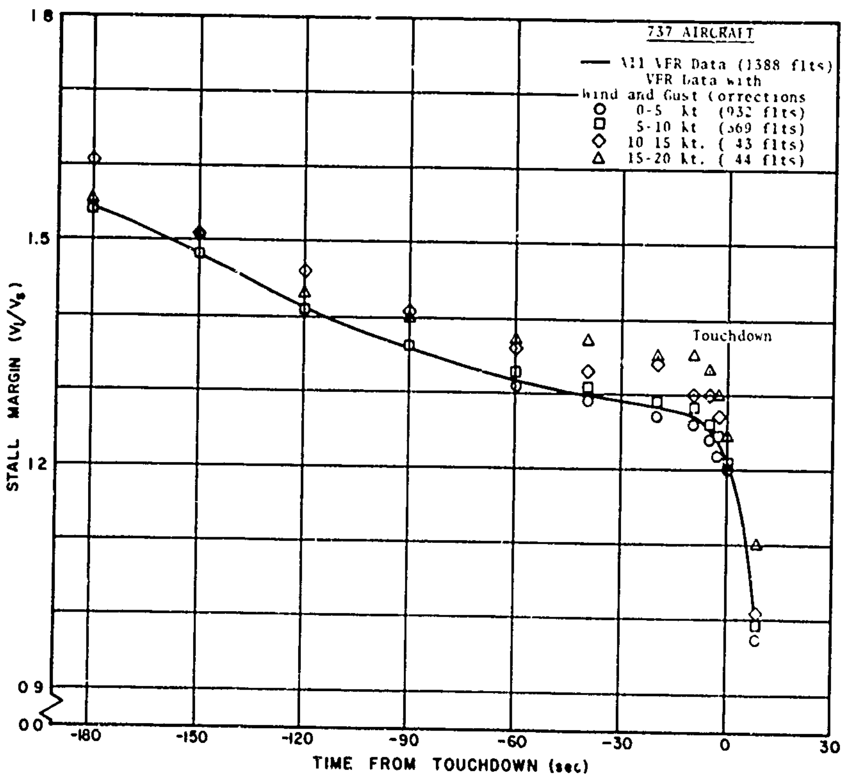


(b) Comparison of IFR Approaches by Ceiling

Figure 11. Time History of Mean Stall Margin During IFR and VFR Approaches

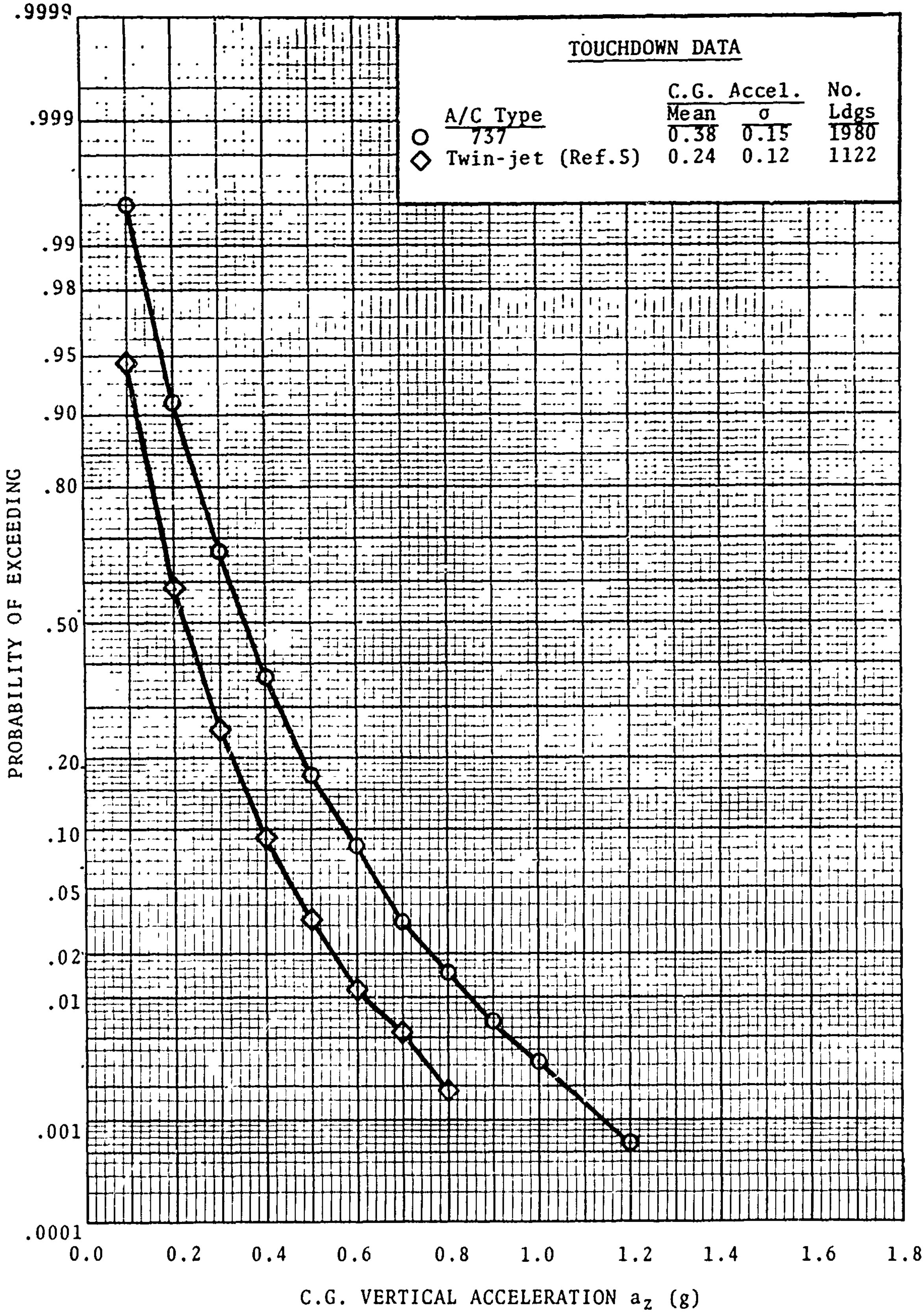


(c) Comparison of IFR Approaches by Wind Speed



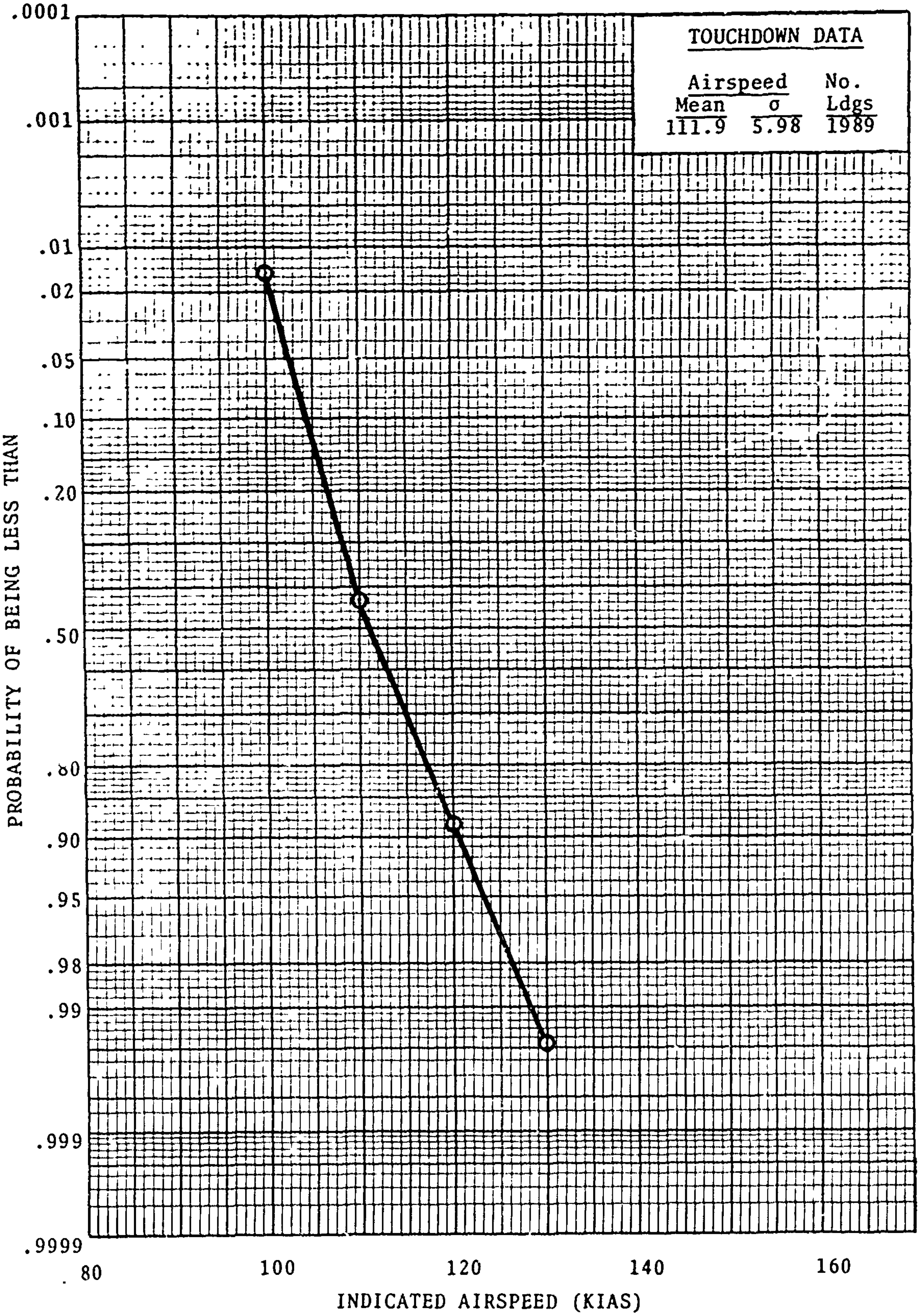
(d) Comparison of VFR Approaches by Wind Speed

Figure 11 - Concluded



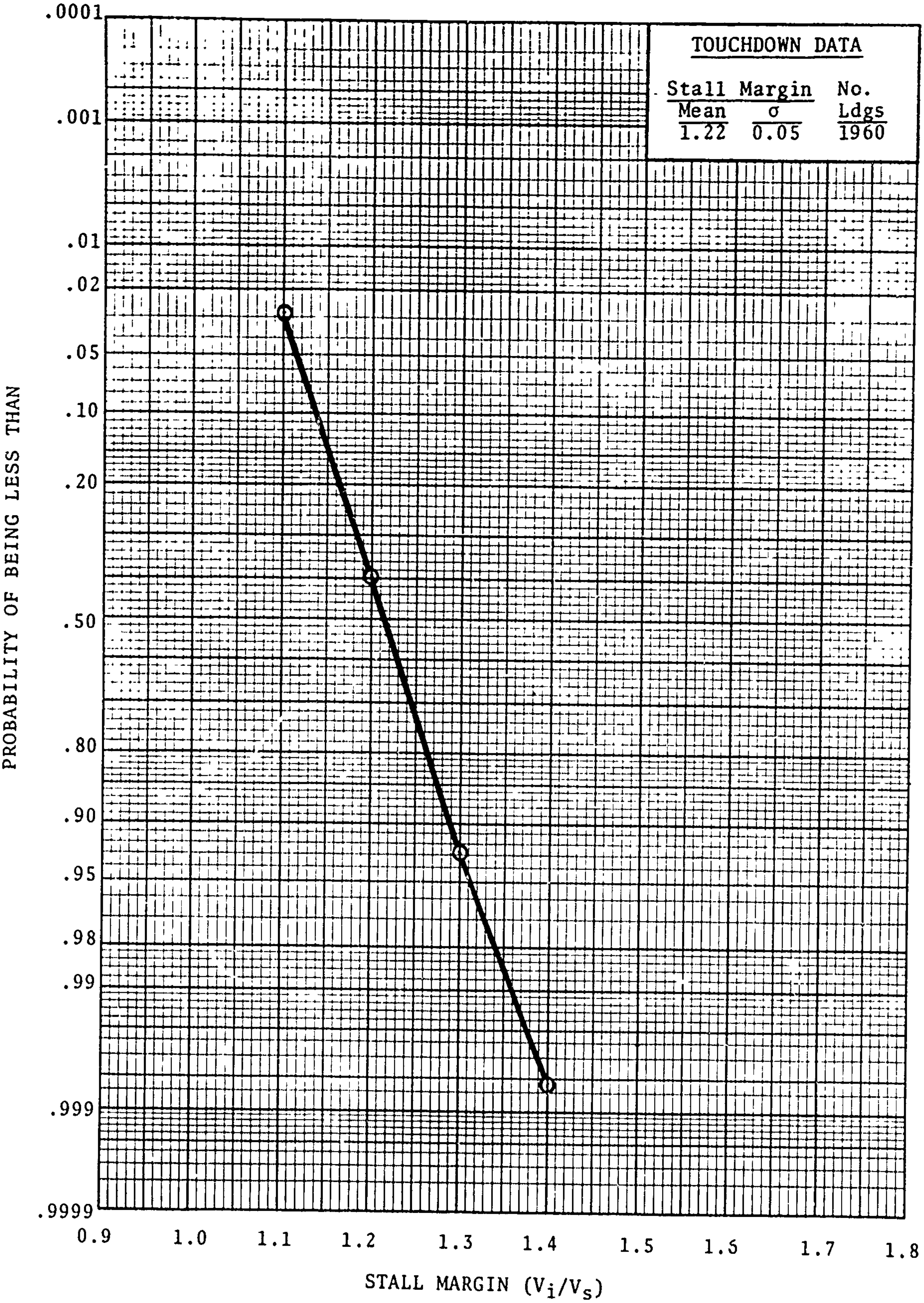
(a) Probability of Exceeding Levels of Vertical Acceleration

Figure 12. Touchdown Data



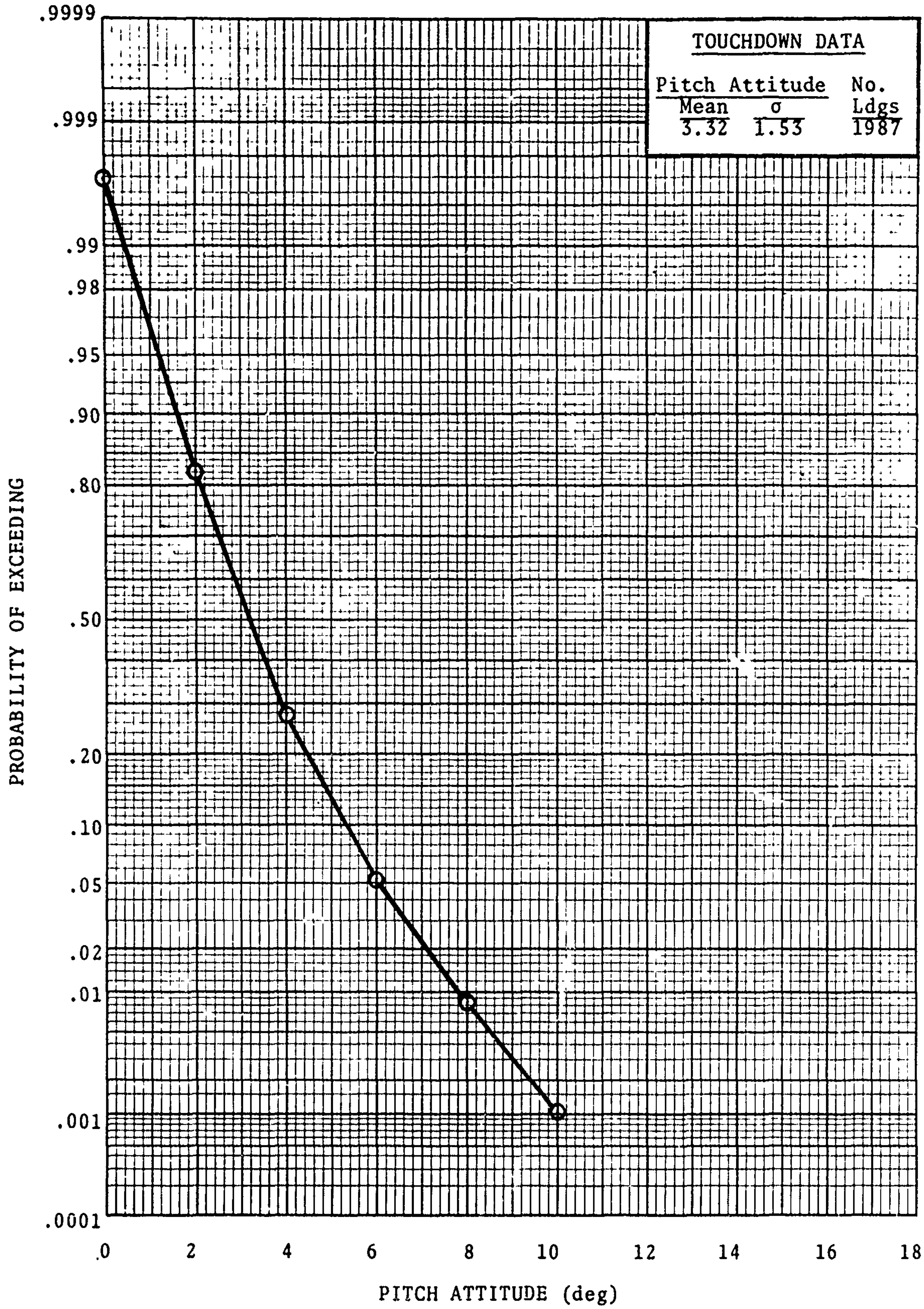
(b) Probability of Being Less Than Levels of Indicated Airspeed

Figure 12 - Continued



(c) Probability of Being Less Than Levels of Stall Margin

Figure 12 - Continued



(d) Probability of Exceeding Levels of Pitch Attitude

Figure 12 - Concluded

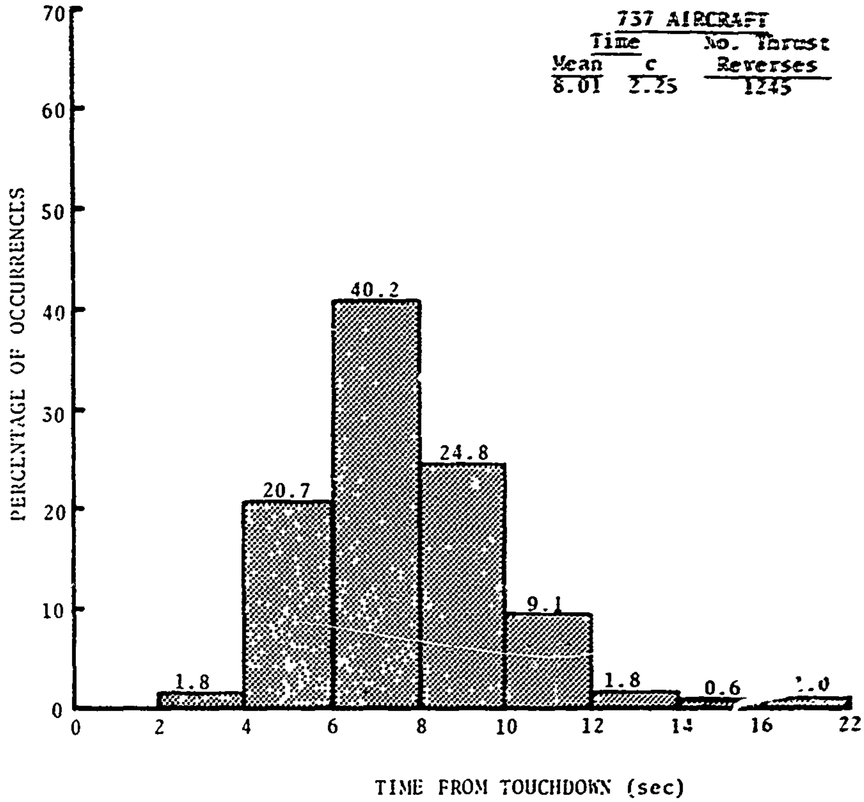


Figure 13. Time from Touchdown to Thrust Reverse During Landings

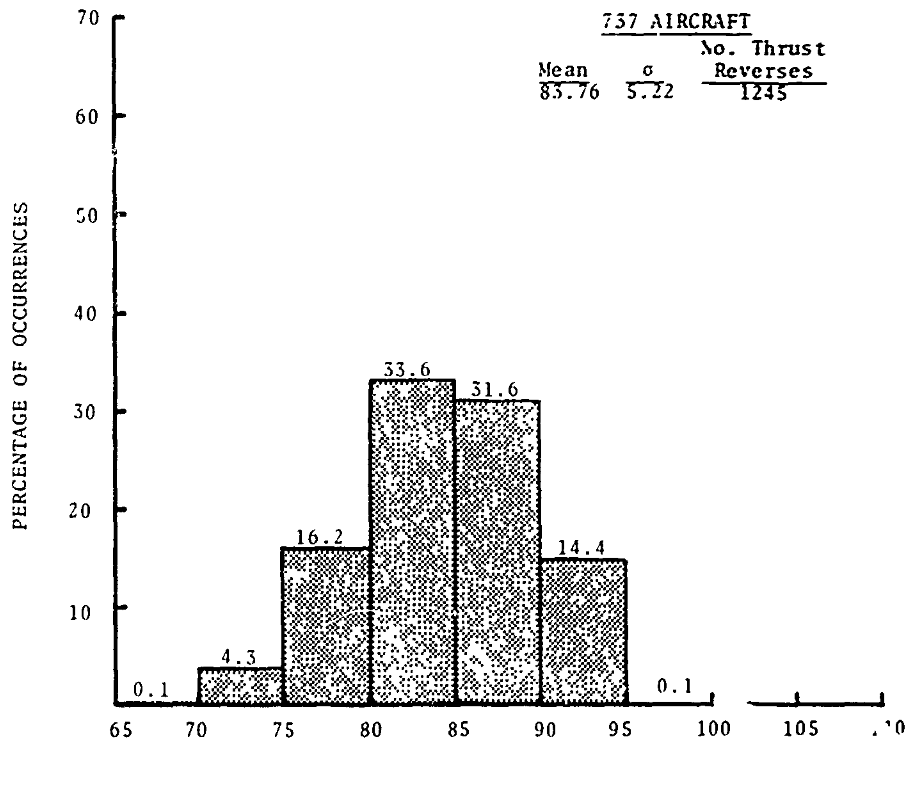


Figure 14. Maximum RPM During Thrust Reverse on Landings by 737 Aircraft

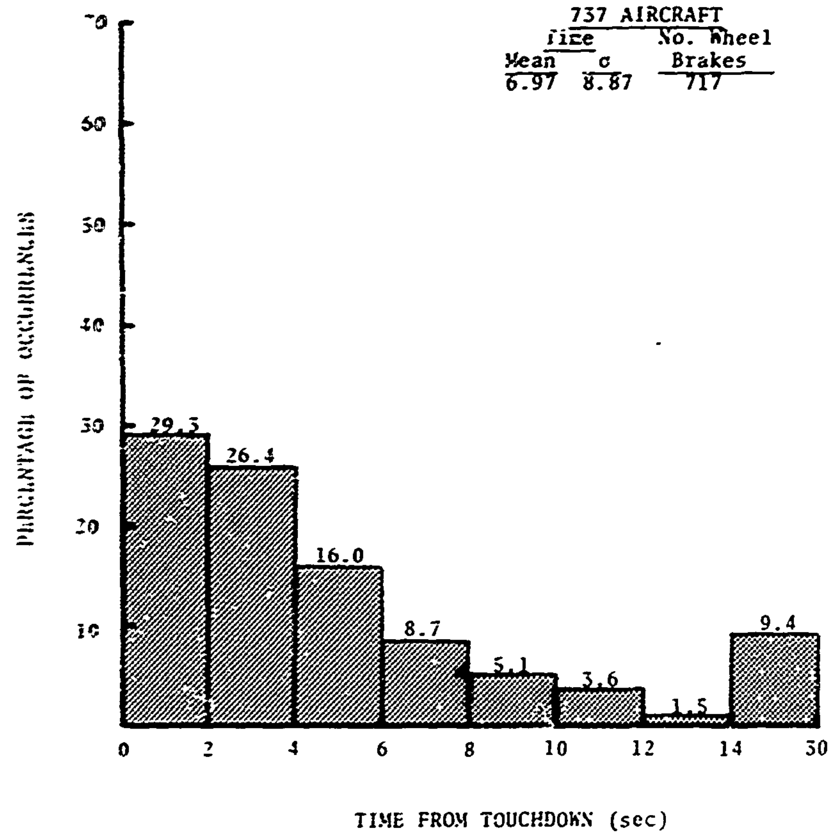


Figure 15. Time from Touchdown to Wheel Brakes Application During Landings

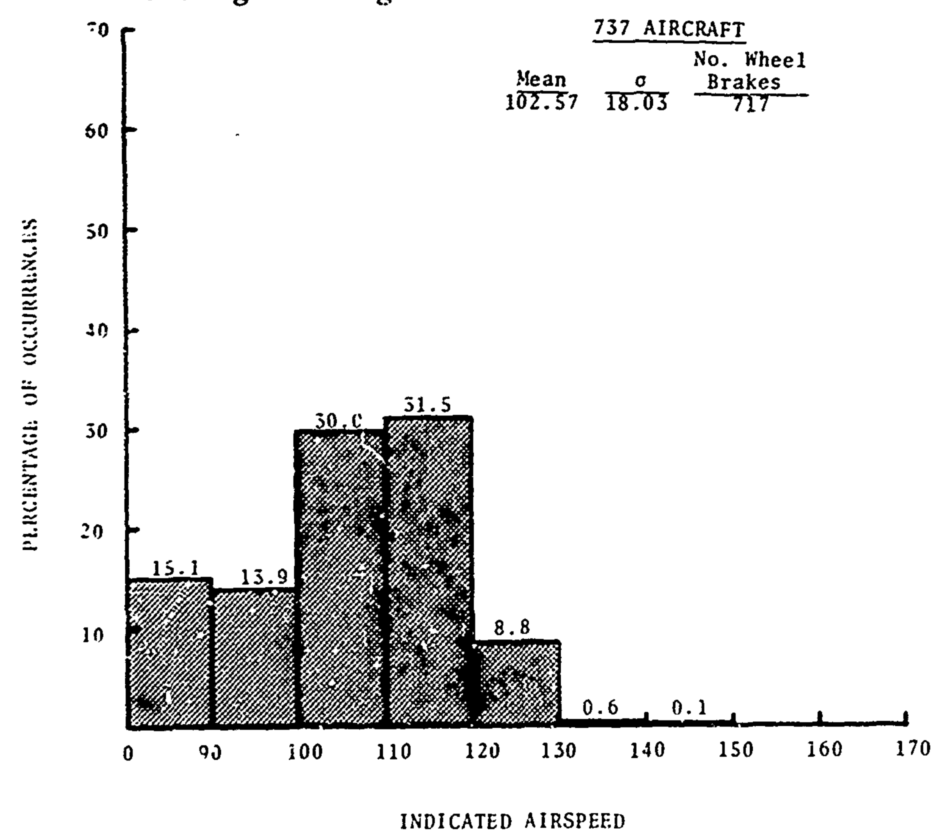
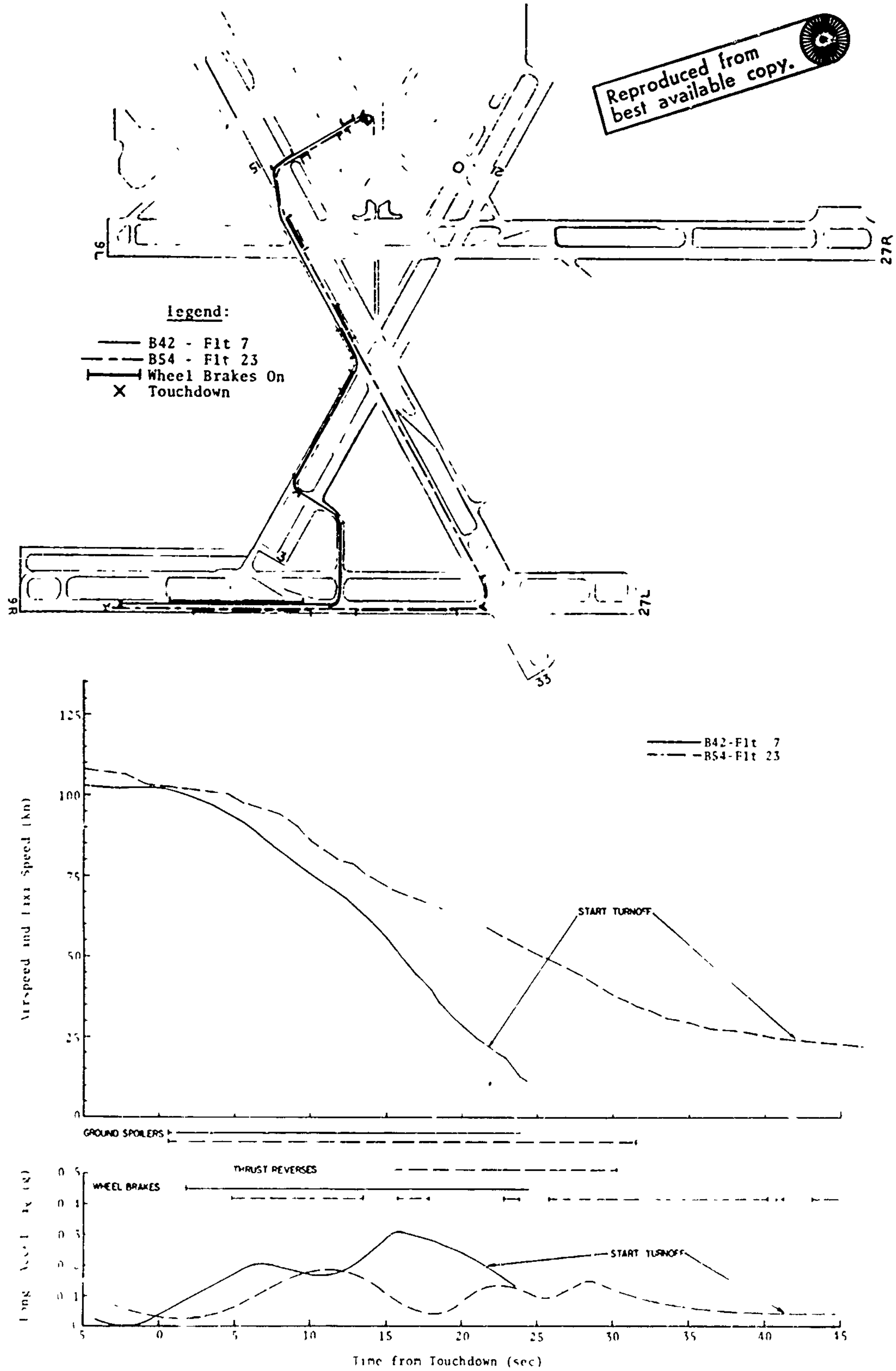
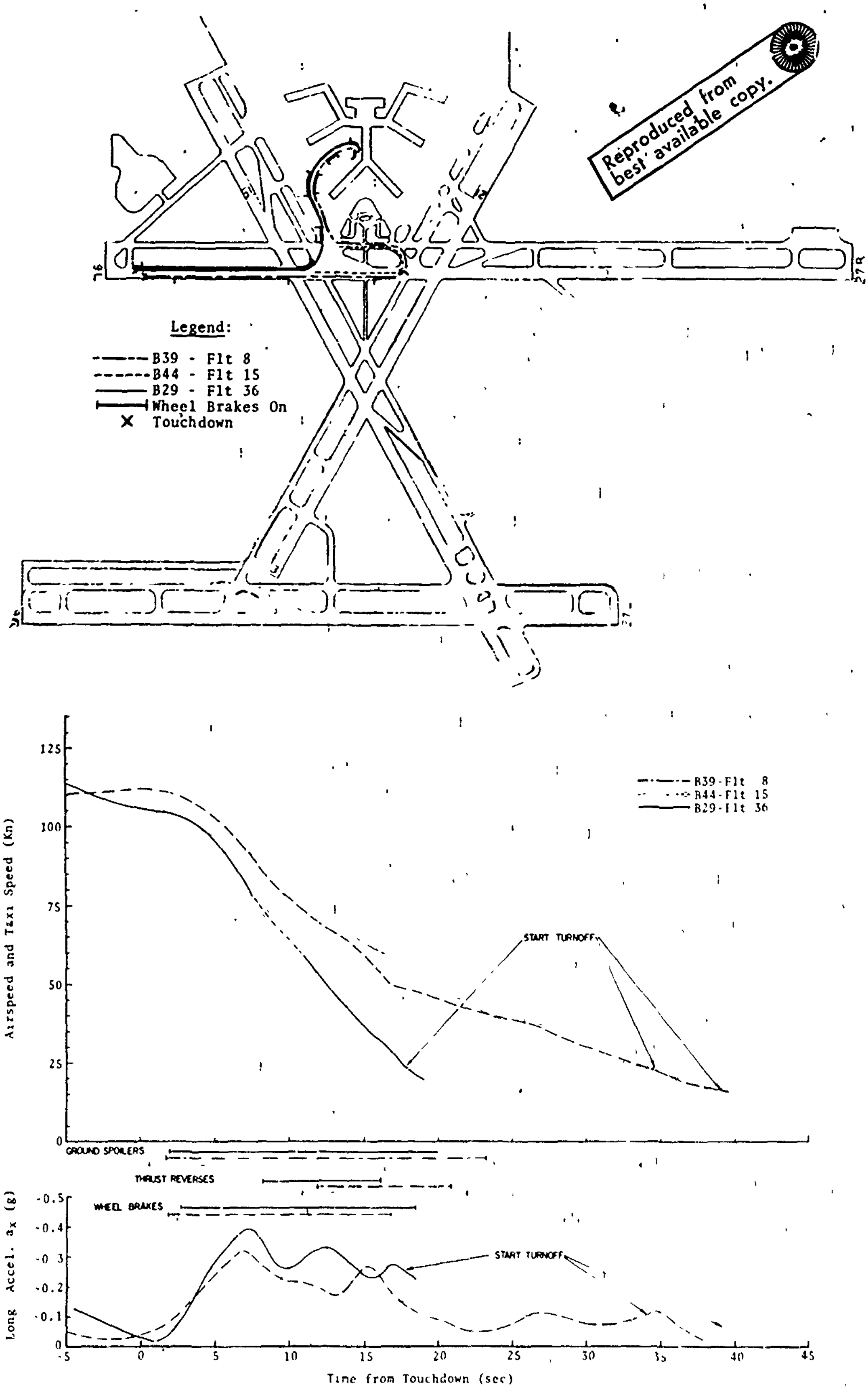


Figure 16. Speed at Wheel Brake Application During Landings



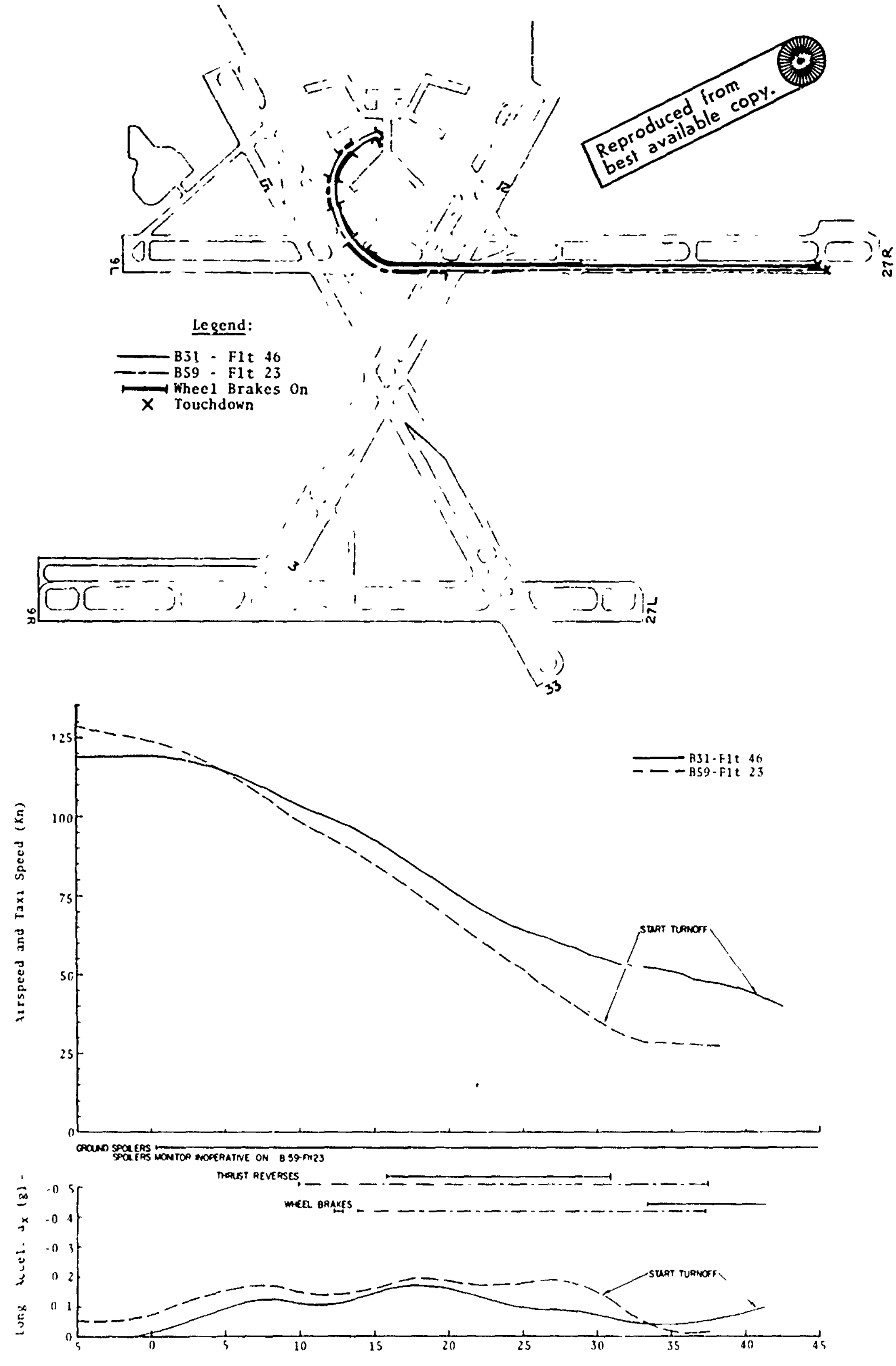
(a) ATL Runway 09R

Figure 17. Time Histories of Ground Track, Taxi Speed, and Deceleration During Typical Arrivals at Atlanta



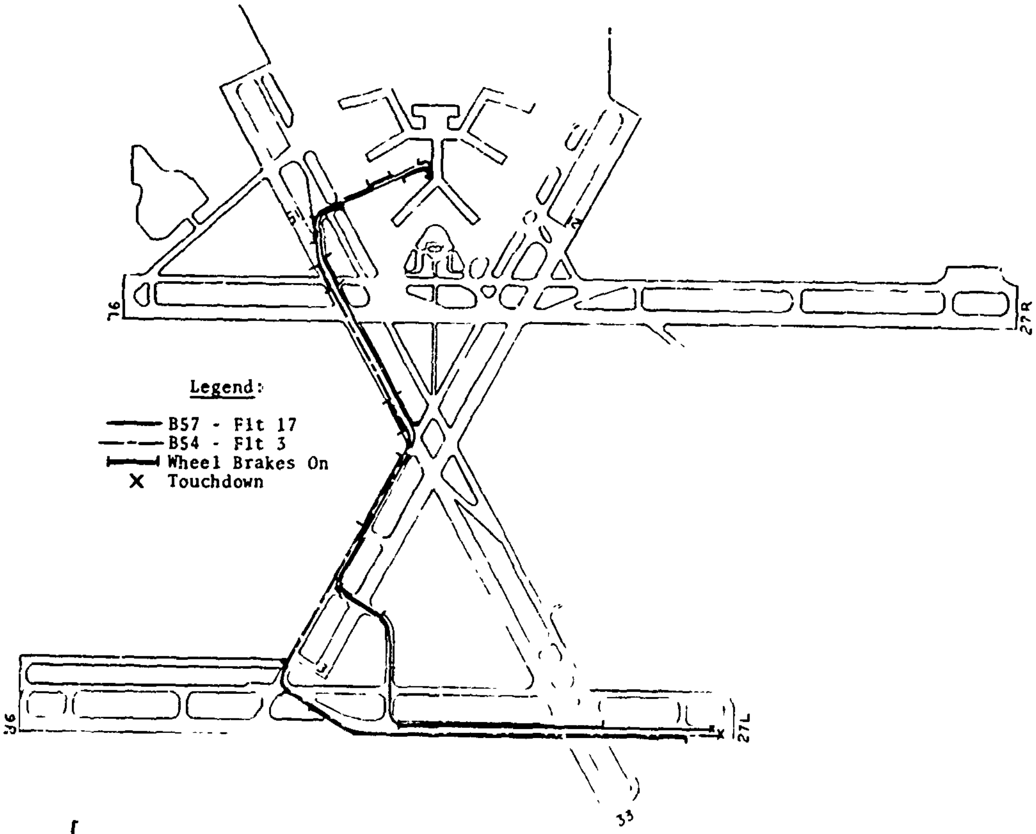
(b) ATL Runway 09L

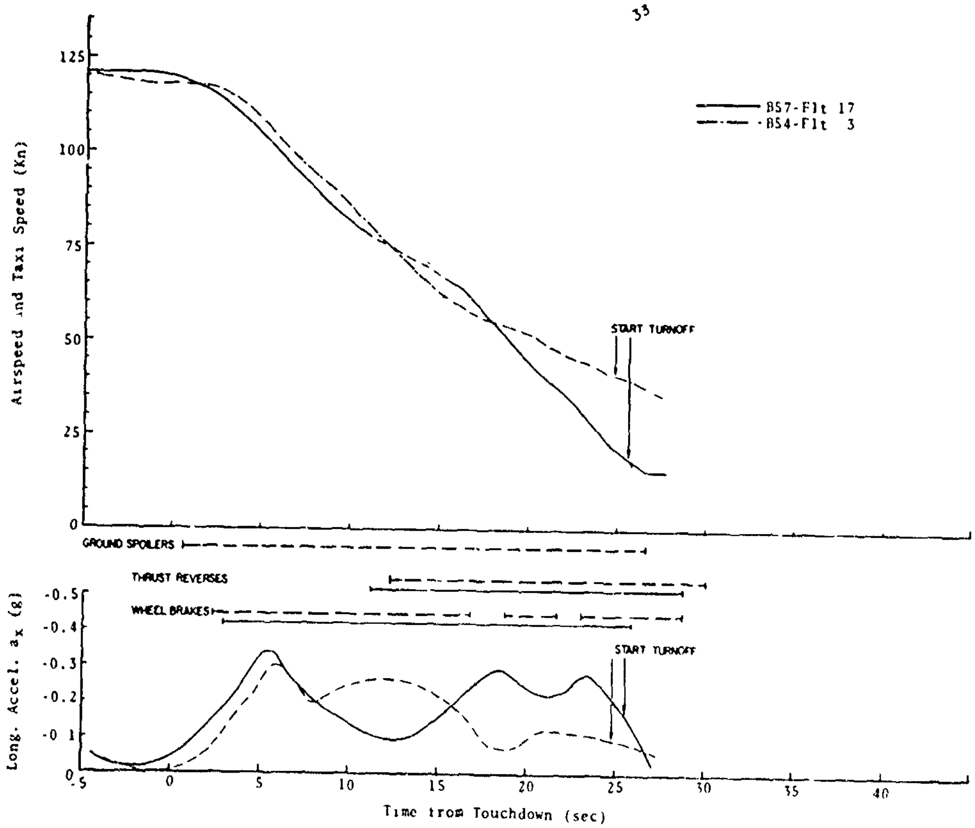
Figure 17 - Continued



(c) ATL Runway 27R

Figure 17 - Continued





(d) ATL Runway 27L
Figure 17 - Concluded

TABLE 9. RUNWAY OCCUPANCY TIMES AND AVERAGE LONGITUDINAL ACCELERATIONS DURING DEPARTURES AND ARRIVALS

AIRPORT			TAKEOFF ROLL			LANDING ROLL		
NAME	CODE	RNWY	NO.	AVG TIME (SEC)	AVERAGE ACCELERATION (G'S)	NO.	AVG TIME (SEC)	AVERAGE ACCELERATION (G'S)
ATLANTA	ATL	09	14	33.0	0.20	10	27.6	-0.19
	ATL	15	1	27.6	0.23	0	--	--
	ATL	27	15	39.6	0.16	11	28.8	-0.18
ASHEVILLE	AVL	16	6	36.6	0.18	7	25.8	-0.20
	AVL	34	15	31.2	0.21	14	33.0	-0.16
NASHVILLE	BNA	02	6	29.4	0.22	7	30.0	-0.17
	BNA	13	0	--	--	1	23.4	-0.22
	BNA	20	12	31.2	0.21	13	31.8	-0.16
	BNA	31	15	39.0	0.17	9	30.6	-0.17
CHARLOTTESVILLE	CHO	03	5	27.0	0.24	4	30.6	-0.17
	CHO	21	3	25.2	0.26	3	30.6	-0.17
CHARLOTTE	CLT	05	15	37.2	0.17	17	30.0	-0.17
	CLT	18	3	33.6	0.19	1	47.4	-0.11
	CLT	23	11	40.8	0.16	11	28.8	-0.48
	CLT	36	1	28.2	0.23	2	60.0	-0.09
WASHINGTON NAT'L	DCA	18	8	44.4	0.15	7	25.2	-0.20
	DCA	33	1	28.2	0.23	3	33.6	-0.15
	DCA	36	2	28.8	0.22	9	23.4	-0.22
NEWARK	EWR	04	0	--	--	2	27.0	-0.19
	EWR	22	2	36.0	0.18	0	--	--
FAYETTEVILLE	FAY	03	32	27.6	0.23	29	30.6	-0.17
	FAY	21	6	27.6	0.23	9	33.0	-0.16
GREENSBORO	GSO	14	2	30.6	0.21	2	37.8	-0.14
	GSO	23	0	--	--	2	70.8	-0.07
	GSO	32	4	35.4	0.18	2	27.6	-0.19
HUNTINGTON	HTS	11	4	42.0	0.15	9	38.4	-0.13
	HTS	29	10	27.6	0.23	3	30.6	-0.17
DULLES	IAD	01	2	30.6	0.21	1	42.6	-0.12
	IAD	19	1	58.8	0.11	2	43.8	-0.12
	IAD	30	2	28.8	0.22	0	--	--
WILMINGTON	ILM	05	3	34.2	0.19	3	33.0	-0.16
	ILM	16	1	30.0	0.22	2	30.6	-0.17
	ILM	34	3	28.8	0.22	4	27.6	-0.19
WINSTON-SALEM	INT	15	7	34.8	0.19	0	--	--
	INT	33	3	34.2	0.19	11	45.6	-0.11
KINGSTON	ISO	04	10	33.0	0.20	11	33.6	-0.15
	ISO	22	8	33.0	0.20	13	28.2	-0.18
LAGUARDIA	LGA	04	5	32.4	0.20	2	23.4	-0.22
	LGA	13	5	32.4	0.20	1	25.2	-0.20
	LGA	22	0	--	--	10	23.4	-0.22
	LGA	31	10	34.8	0.19	11	25.2	-0.20
LEXINGTON	LEX	04	2	31.8	0.20	3	34.2	-0.15
	LEX	22	9	33.0	0.20	6	31.8	-0.16
LYNCHBURG	LYH	03	3	27.0	0.24	6	33.0	-0.16
	LYH	21	6	27.6	0.23	2	25.8	-0.20
MIDWAY, CHICAGO	MDW	04	1	28.8	0.22	3	25.8	-0.20
	MDW	13	5	36.6	0.18	7	34.2	-0.15
	MDW	22	6	42.6	0.15	6	25.8	-0.20
	MDW	31	5	29.4	0.22	4	48.6	-0.11
MEMPHIS	MEM	09	0	--	--	1	25.8	-0.20
	MEM	17	3	37.2	0.17	4	25.8	-0.20
	MEM	27	0	--	--	1	42.0	-0.12
	MEM	35	7	29.4	0.22	9	28.8	-0.18
NORFOLK	ORF	04	24	33.0	0.20	25	29.4	-0.18
	ORF	22	23	30.0	0.22	10	28.2	-0.18
	ORF	31	1	26.4	0.24	2	40.2	-0.13
RICHMOND	RIC	02	27	34.2	0.19	19	31.8	-0.16
	RIC	06	0	--	--	2	28.2	-0.17
	RIC	15	6	25.2	0.26	0	--	--
	RIC	20	24	30.6	0.21	21	38.4	-0.13
	RIC	33	1	34.8	0.19	11	70.2	-0.07
ROANOKE	ROA	05	5	30.6	0.21	1	52.8	-0.10
	ROA	15	10	30.6	0.21	4	31.2	-0.17
	ROA	23	50	33.0	0.20	23	30.6	-0.17
	ROA	33	4	42.6	0.15	37	27.0	-0.19
RALEIGH-DURHAM	RDU	05	8	32.4	0.20	11	35.4	-0.15
	RDU	23	14	36.6	0.18	14	33.6	-0.15
LOUISVILLE	SDF	01	0	--	--	2	39.6	-0.13
	SDF	19	2	34.8	0.19	1	28.8	-0.18
	SDF	29	1	46.2	0.14	3	57.0	-0.09
TRI-CITY, TENN.	TRI	04	1	29.4	0.22	2	30.0	-0.17
	TRI	22	12	31.2	0.21	12	27.6	-0.19
	TOTAL		513	[illegible].0	0.20	513	32.4	-0.16

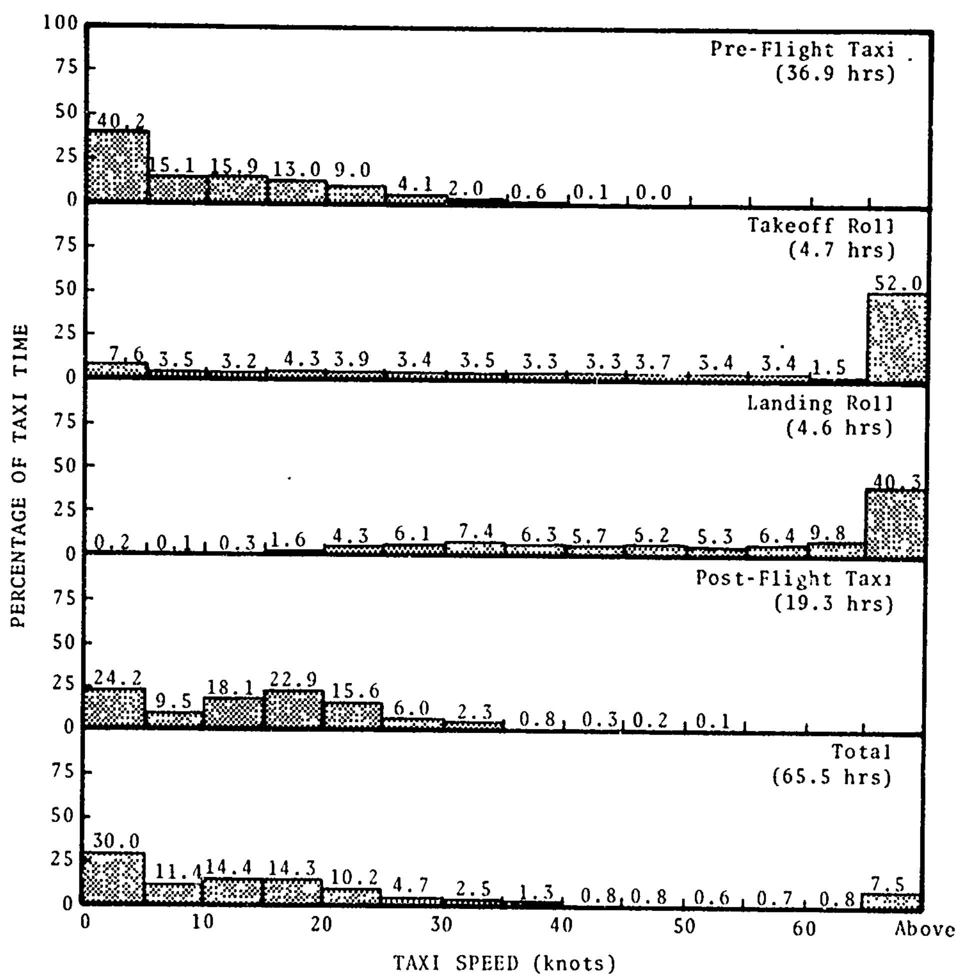


Figure 18. Percentage of Taxi Time Spent in Each Interval of Taxi Speed

TABLE 10. NUMBER OF TURNS DURING DEPARTURE TAXI AND ARRIVAL TAXI FOR EACH RUNWAY

(a) Pre-flight Taxi Data

TURNS PER FLIGHT FOR AIRPORT, RUNWAY BY PREFLT TAXI

AIRPORT	RUNWAY	0	1	2	3	4	5	6	7	8	9	TOTAL FLIGHTS	TOTAL TURNS
						TURNS PER FLIGHT							
ATL	09		3	1		4	1	4				13	50
ATL	15					1						1	4
ATL	27		1	1		2	3	5		2		14	72
AVL	16				1	4		1				6	25
AVL	34			2	1	10	2					15	57
BNA	02					3		3				6	30
BNA	20					2	6	2	1		1	12	68
BNA	31			2		7	5	1				15	63
CHO	03					1	4					5	24
CHO	21			2		1						3	8
CLT	05		1			1	3	5	4			14	78
CLT	18						1	1		1		3	19
CLT	23		2		1	4	2	2				11	43
CLT	36				1							1	3
DCA	18		3	2			1	2				8	24
DCA	33				1							1	3
DCA	36		1			1						2	5
EWR	22				1	1						2	7
FAY	03		1	3	10	10	7	1				32	118
FAY	21		1	1	1	2	1					6	19
GSO	14		1				1					2	6
GSO	32			1	2		1					4	13
HTS	11			2	2							4	10
HTS	29		1		6	3						10	31
IAD	01				1	1						2	7
IAD	19					1						1	4
IAD	30					2						2	8
ILM	05						2		1			3	17
ILM	16				1							1	3
ILM	34				1	1	1					3	12
INT	15		1		5		1					7	21
INT	33				2				1			3	13
ISO	04			1	3	2	4					10	39
ISO	22				1	1	5			1		8	40
LGA	04							3	1	1		5	33
LGA	13		2				1	1		1		5	21
LGA	31			1	1		2	4	2			10	53
MDW	04						1					1	5
MDW	13				1	2	1	1				5	22
MDW	22		2		3			1				6	17
MDW	31					1	4					5	24
MEM	17					3						3	12
MEM	35			1		4	2					7	28
ORF	04		1	6	14	3						24	67
ORF	22		1	2	8	8	3	1				23	82
ORF	31					1						1	4
RIC	02		1	1	8	8	7	2				27	106
RIC	15			1		1		2	2			6	32
RIC	20		1			2	5	15				23	124
RIC	33										1	1	10
ROA	05		2		1		1	1				5	16
ROA	15		2	6	2							10	20
ROA	23		2	25	15	5	2					49	127
ROA	33				3	1						4	13
SDF	19				1							1	3
SDF	29								1			1	7
TRI	04					1						1	4
TRI	22			1	1	4	5	1				12	52
LEX	04					2						2	8
LEX	22			2	1		5	1				9	38
LYH	03					3						3	12
LYH	21			1	4	1						6	18
RDU	05			1	5	2						8	25
RDU	23		2	1	3	6	2					14	47
TOTAL			32	67	113	123	92	60	13	6	2	507	1974

TABLE 10 - Concluded

(b) Post-flight Taxi Data

TURNS PER FLIGHT FOR AIRPORT, RUNWAY BY POSTFLT TAXI

		TURNS PER FLIGHT											
AIRPORT	RUNWAY	0	1	2	3	4	5	6	7	8	9	TOTAL FLIGHTS	TOTAL TURNS
ATL	09			1	4	1	3		1			10	40
ATL	27			1	4	2	2		1			10	39
AVL	16			2	3	1		1				7	23
AVL	34		2	1	8	2	1					14	41
BNA	02			1	3	3						7	23
BNA	13				1							1	3
BNA	20				2	4	4	2		1		13	62
BNA	31			2	7							9	25
CHO	03		2		2							4	8
CHO	21				1		2					3	13
CLT	05			14	2	1						17	38
CLT	18			1								1	2
CLT	23			2	5	3		1				11	37
CLT	36		1	1								2	3
DCA	18			3	1	3						7	21
DCA	33				1	2						3	11
DCA	36			1	4	4						9	30
EWR	04			1		1						2	6
FAY	03		1	4	14	8	2					29	93
FAY	21			1	2	4	2					9	34
GSO	14				1	1						2	7
GSO	23				1	1						2	7
GSO	32			1	1							2	5
HTS	11			5	3	1						9	23
HTS	29				3							3	9
IAD	01					1						1	4
IAD	19					2						2	8
ILM	05						2	1				3	16
ILM	16					2						2	8
ILM	34				4							4	12
INT	33			6	3	1						10	25
ISO	04		1		2	8						11	39
ISO	22			2	10							12	34
LGA	04							1			1	2	15
LGA	13						1					1	5
LGA	22				1	1	1	2	4		1	10	61
LGA	31		1	1	5	2	2					11	36
MDW	04			1	2							3	8
MDW	13			5	2							7	16
MDW	22				4	2						6	20
MDW	31			1	3							4	11
MEM	09										1	1	9
MEM	17		1	1	1	1						4	10
MEM	27						1					1	5
MEM	35						3	5	1			9	52
ORF	04		3	17	3	2						25	54
ORF	22		2	5	2	1						10	22
ORF	31						1	1				2	11
RIC	02			1	3	4	11					19	82
RIC	06							1	1			2	13
RIC	20			3	1	8	9					21	86
RIC	24					1	2					3	14
RIC	33					1	6	3			1	11	61
ROA	05			1								1	2
ROA	15			2	2							4	10
ROA	23		2	8	8	2		1				21	56
ROA	33		8	22	5	2						37	75
SDF	01				1	1						2	7
SDF	19							1				1	6
SDF	29				3							3	9
TRI	04				2							2	6
TRI	22				1	5	4	1				11	49
LEX	04		1	1	1							3	6
LEX	22				5	1						6	19
LYH	03		2	3		1						6	12
LYH	21					1	1					2	9
RDU	05		1	6	3							10	22
RDU	23			3	10	1						14	40
TOTAL			28	131	160	93	60	21	8	1	4	506	1668

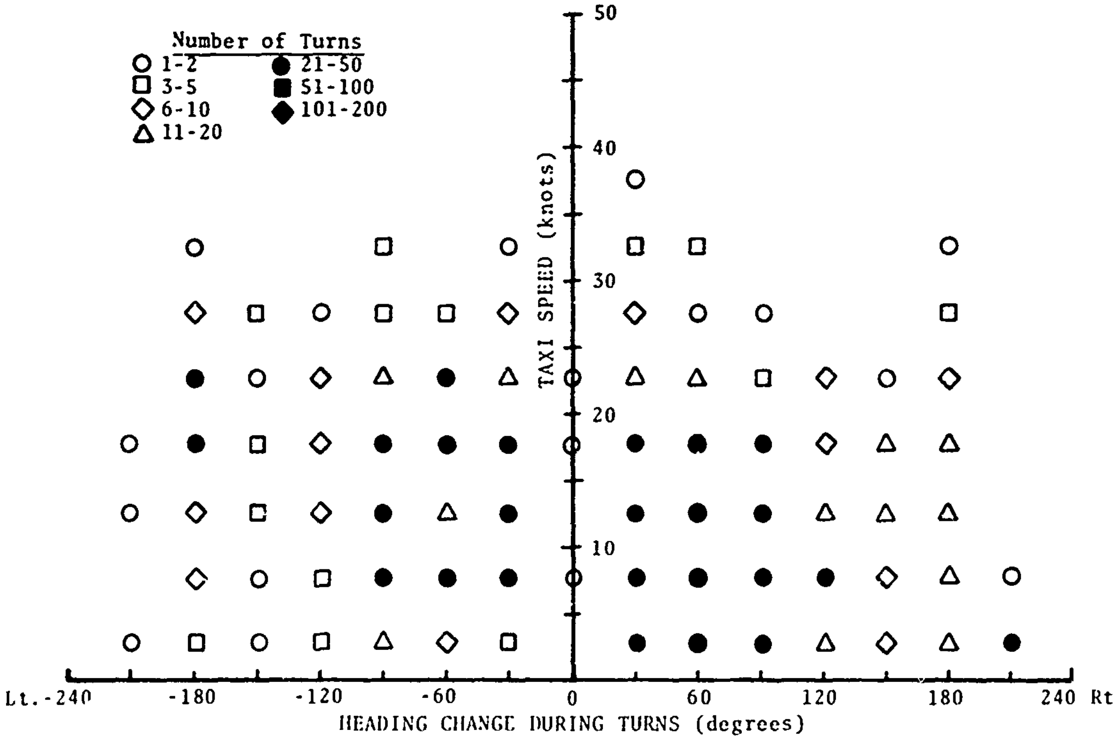


Figure 19. Heading Change in Turns versus Taxi Speed at Start of Turn

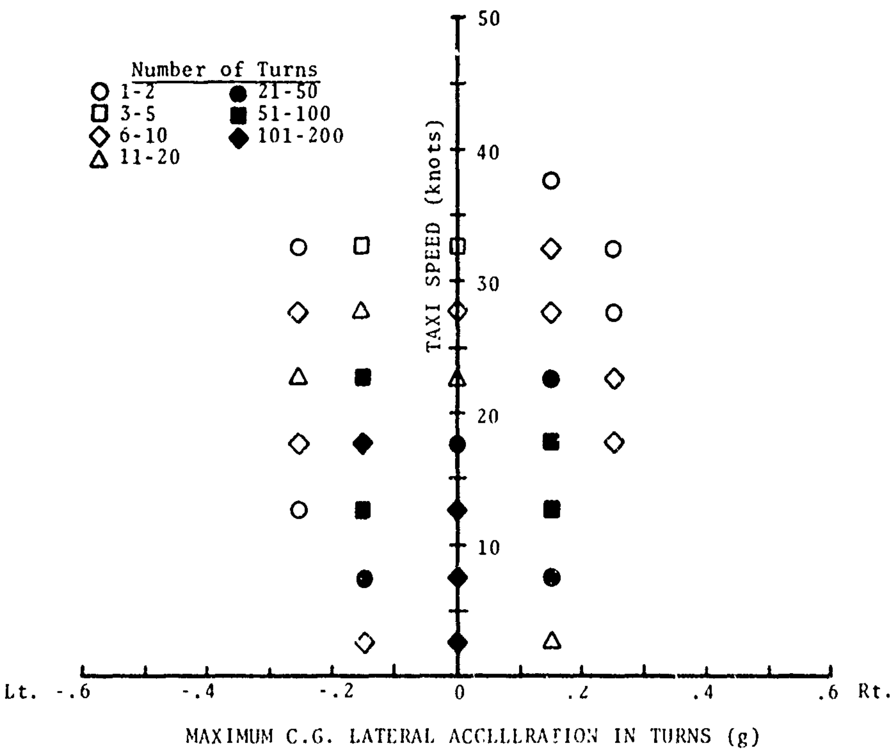


Figure 20. Maximum C.G. Lateral Acceleration in Turns versus Taxi Speed at Start of Turn

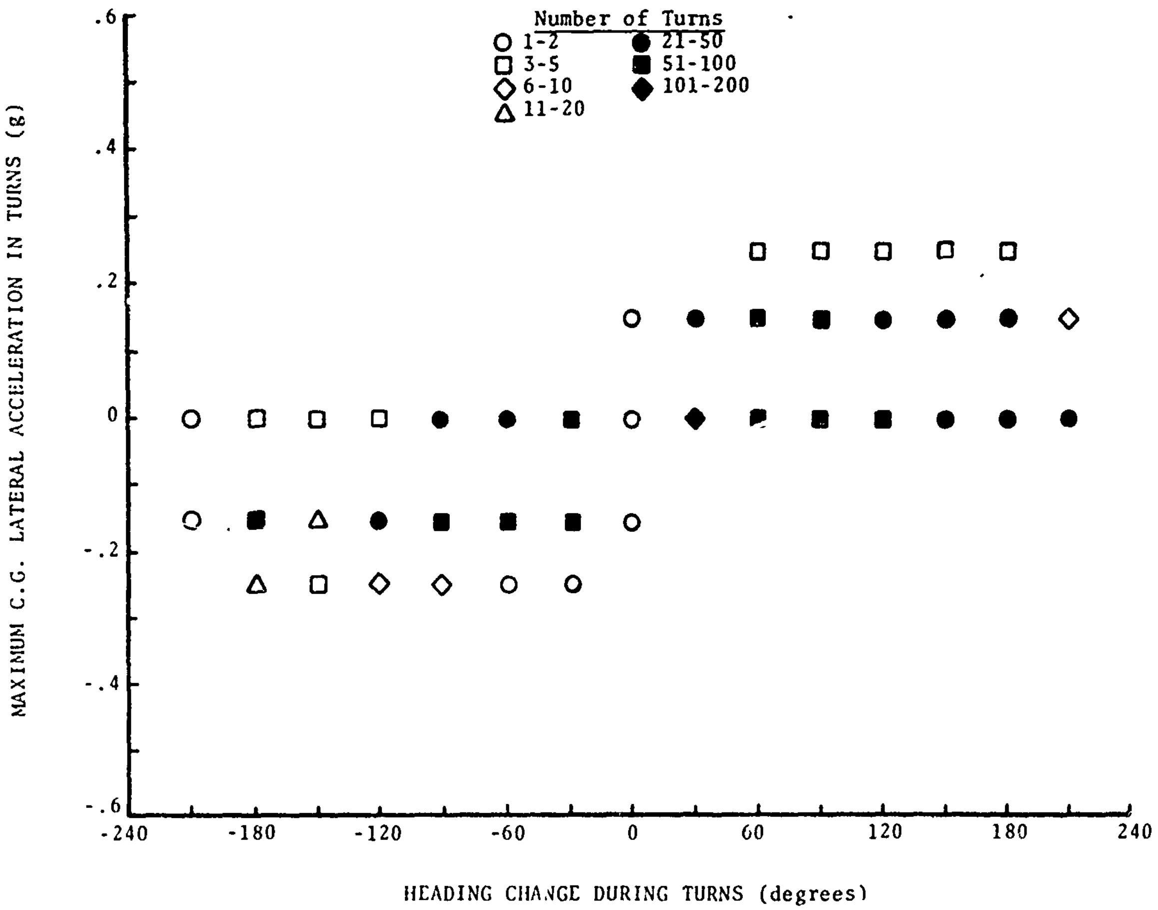


Figure 21. Maximum C.G. Lateral Acceleration in Turns versus Heading Change

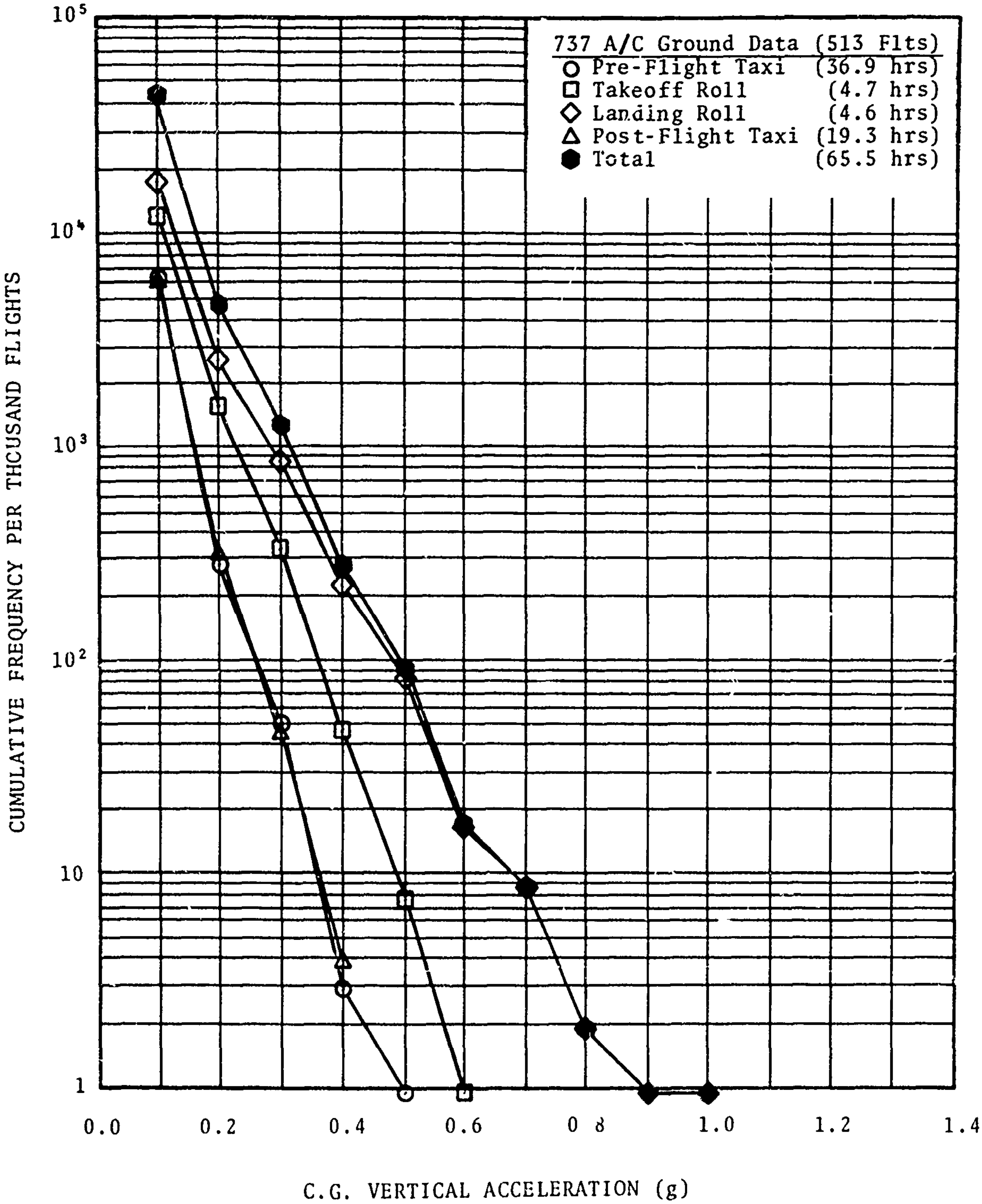


Figure 22. Incremental C.G. Vertical Acceleration Peaks per 1000 Flights by Taxi Phase

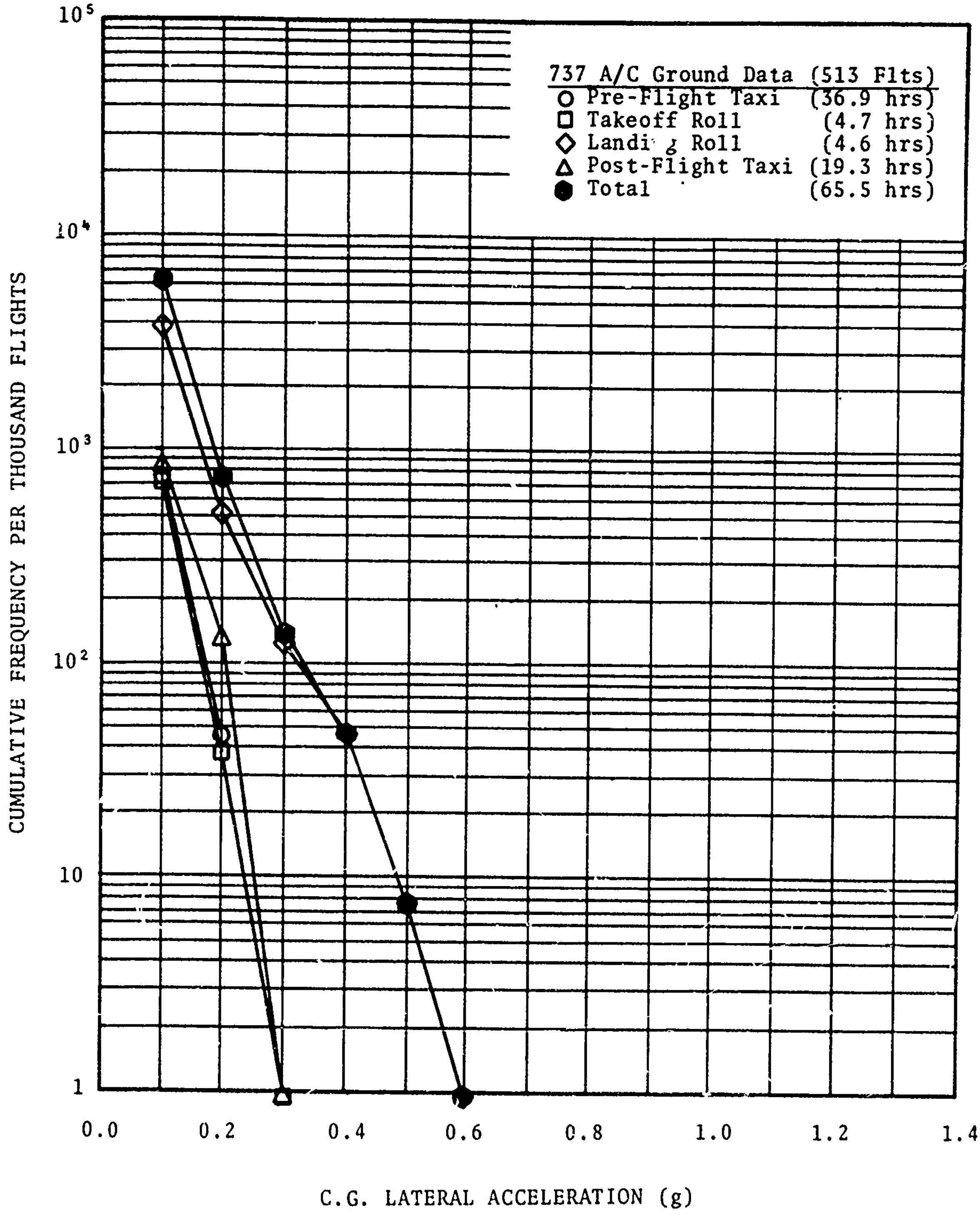


Figure 23. Incremental C.G. Lateral Acceleration Peaks per 1000 Flights by Taxi Phase

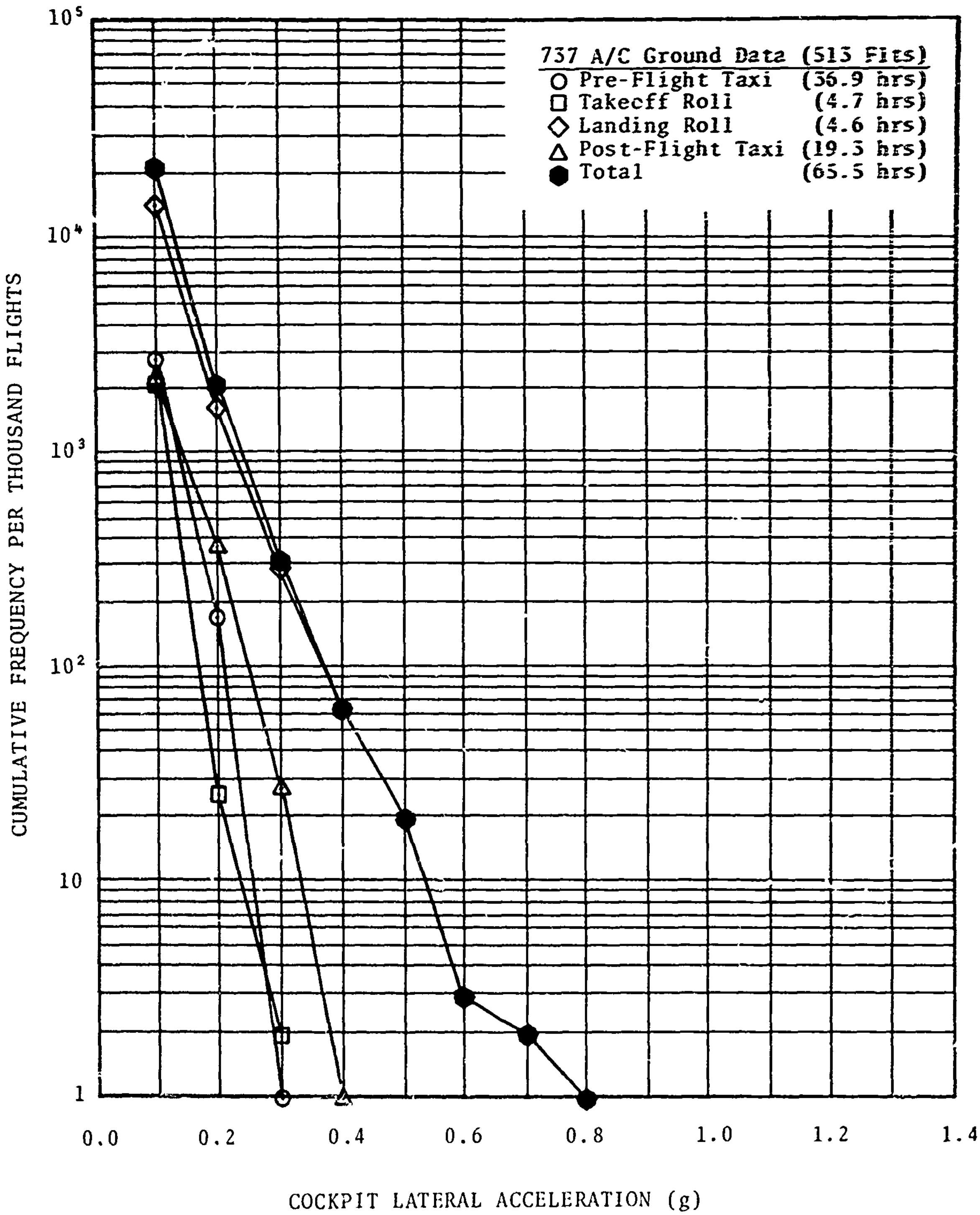


Figure 24. Incremental Cockpit Lateral Acceleration Peaks per 1000 Flights by Taxi Phase

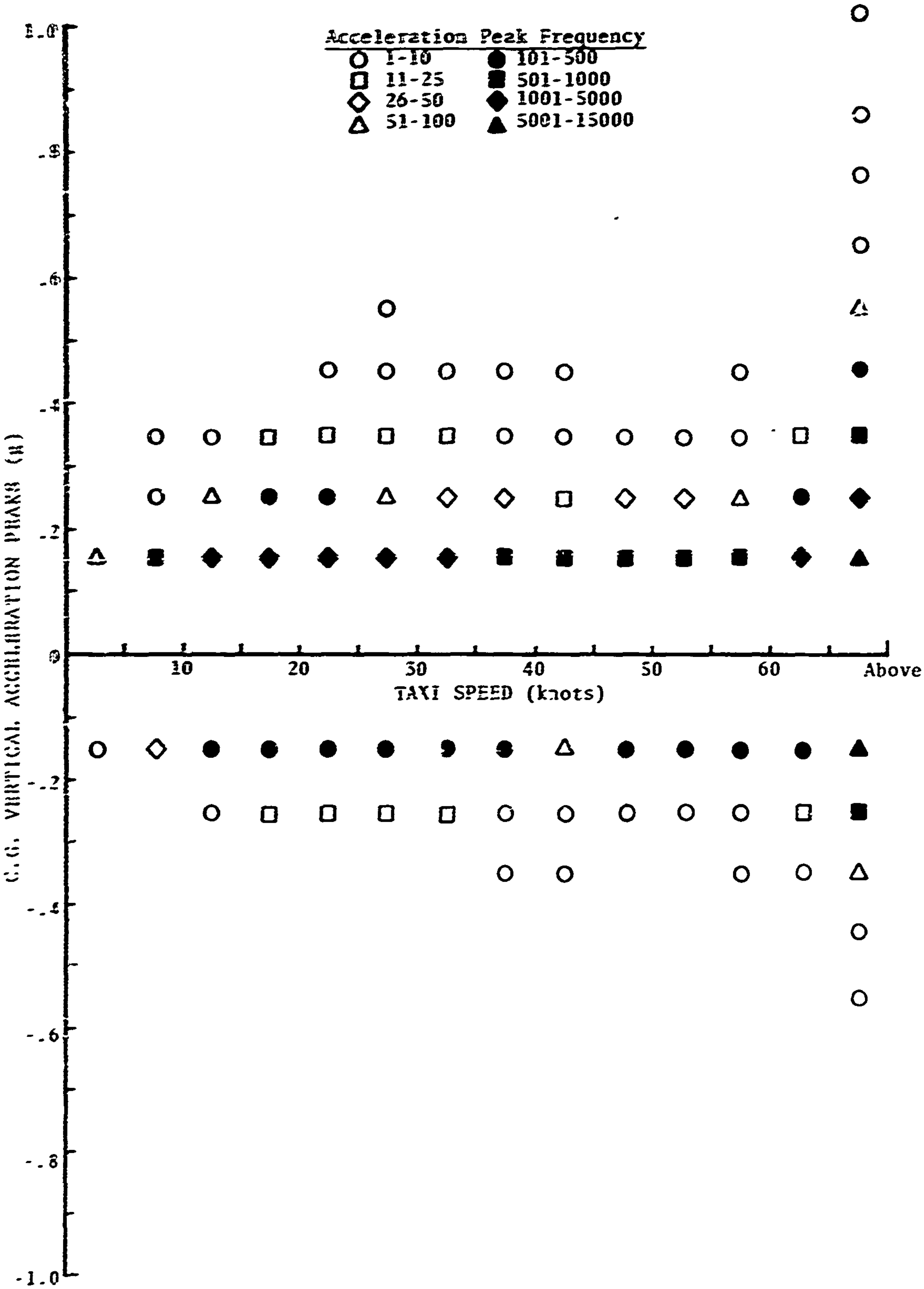


Figure 25. Vertical Acceleration Peaks at the C.G. versus Taxi Speed

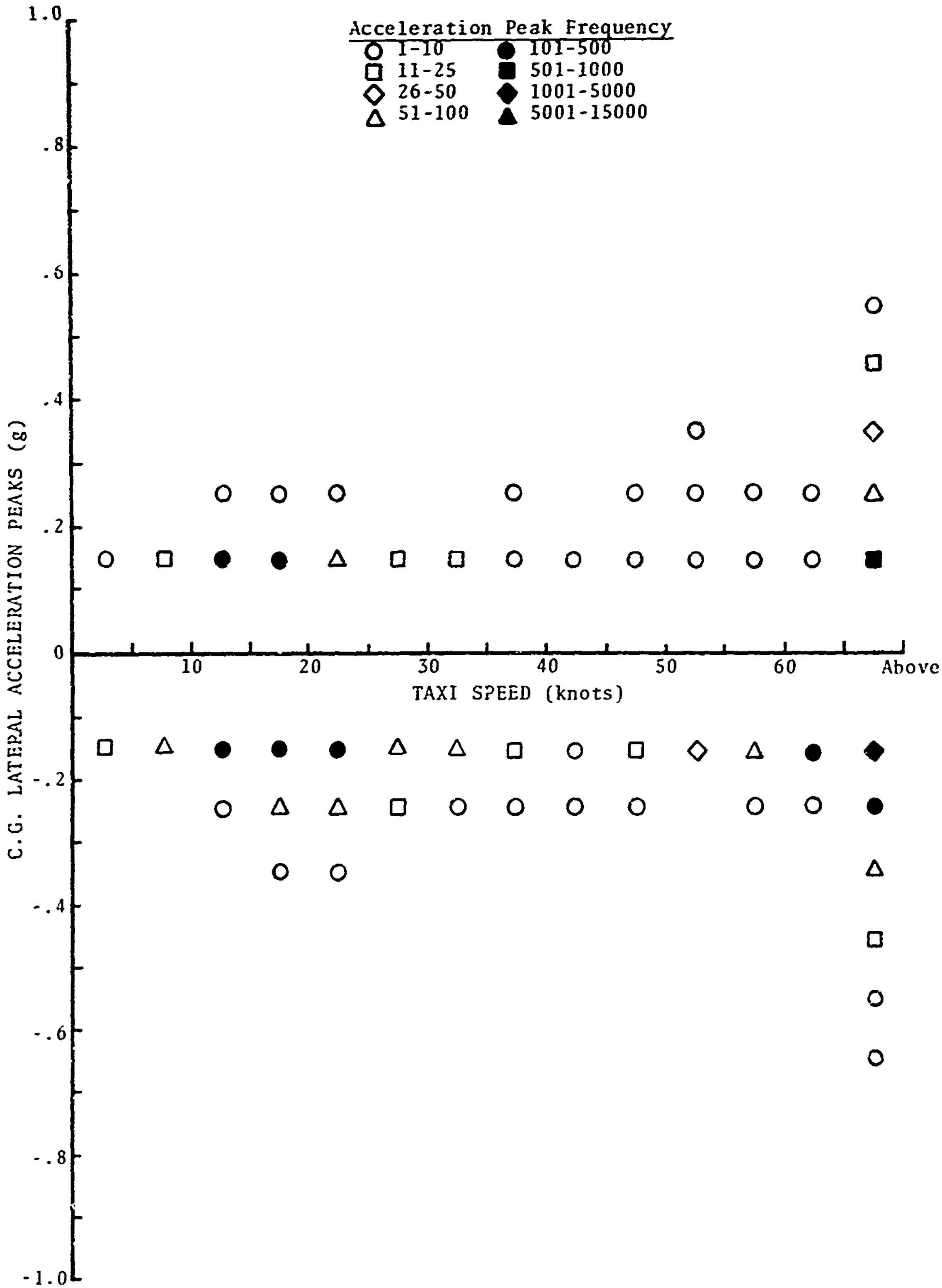


Figure 26. Lateral Acceleration Peaks at the C.G. versus Taxi Speed

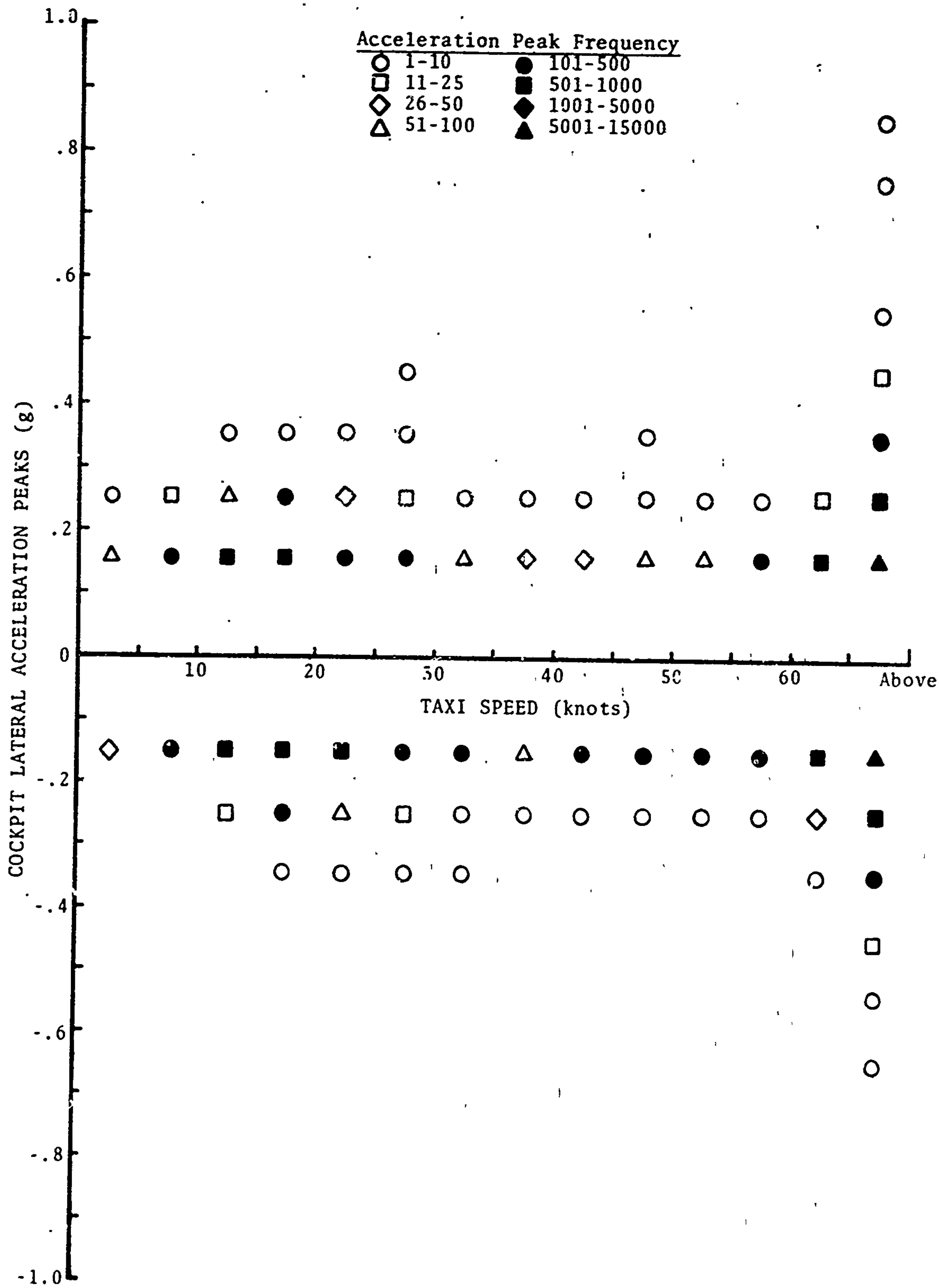
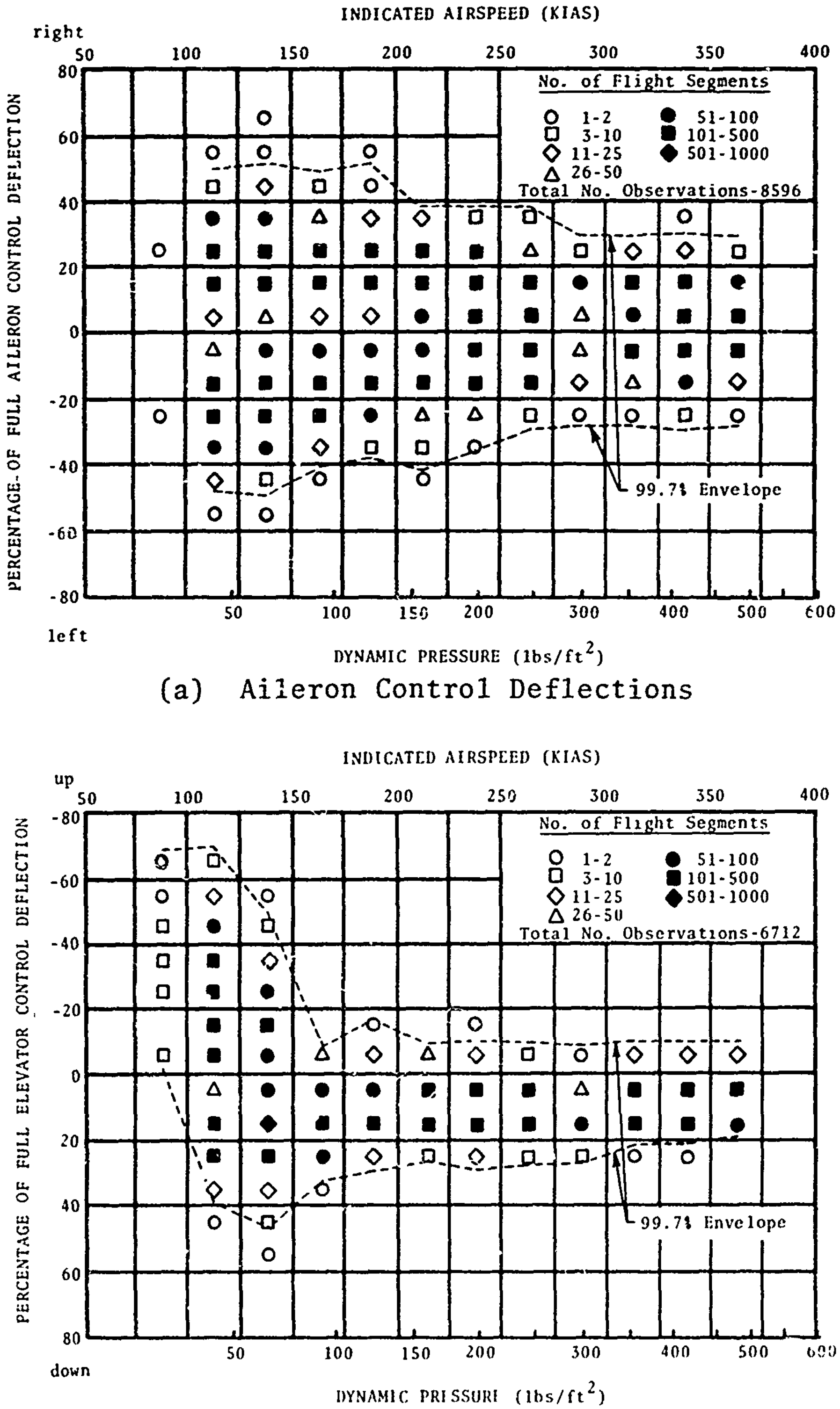


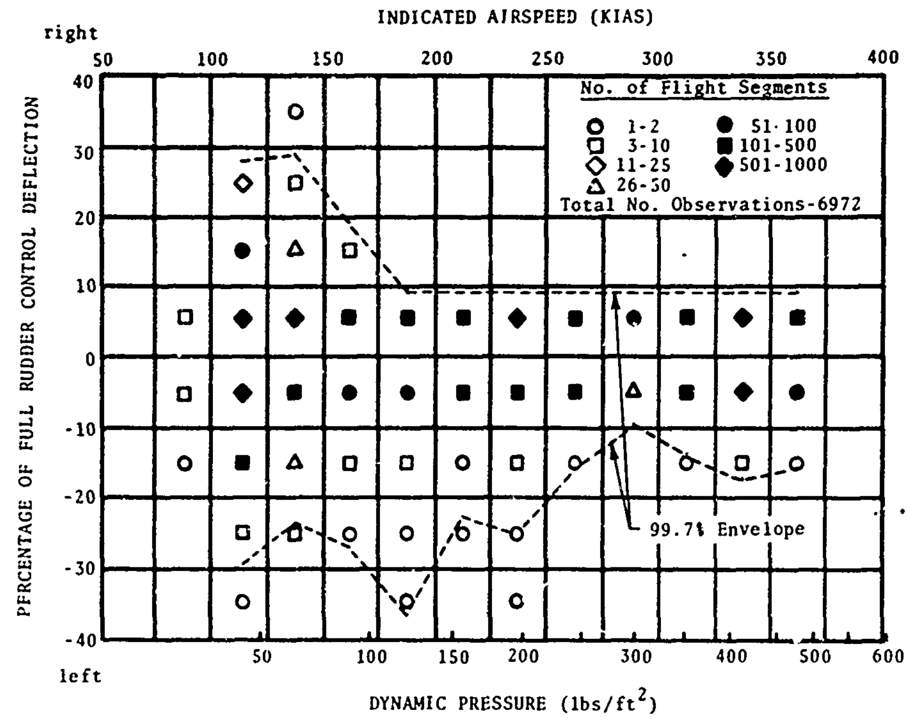
Figure 27. Cockpit Lateral Acceleration versus Taxi Speed



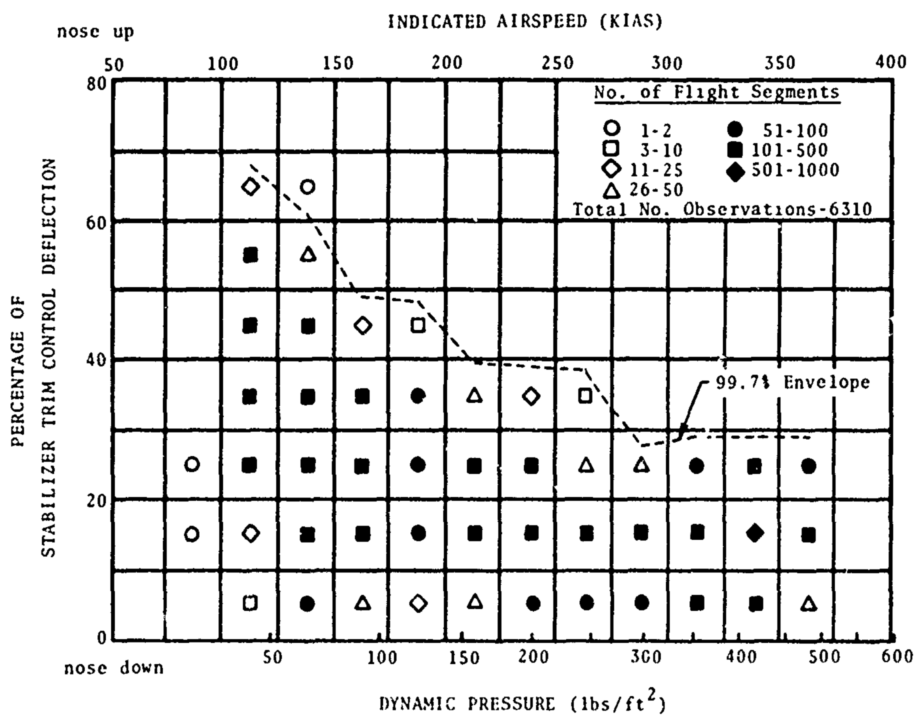
(a) Aileron Control Deflections

(b) Elevator Control Deflections

Figure 28. Maximum Flight Control Deflections During Each Recorded Flight Segment versus Dynamic Pressure

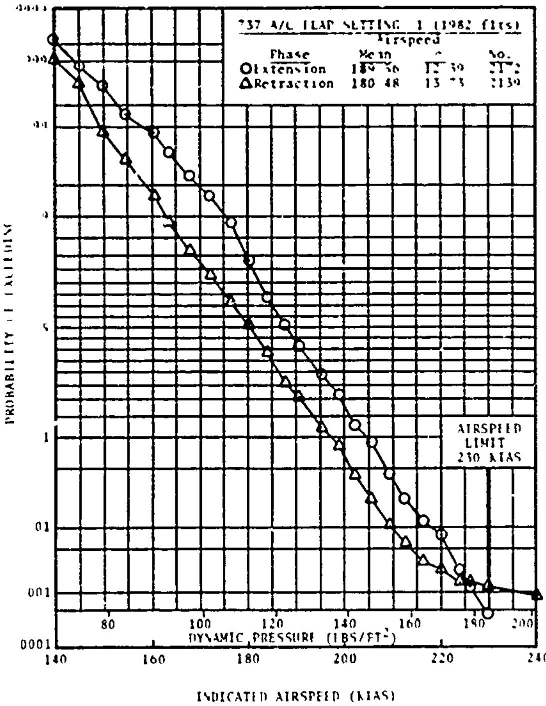


(c) Rudder Pedal Deflections

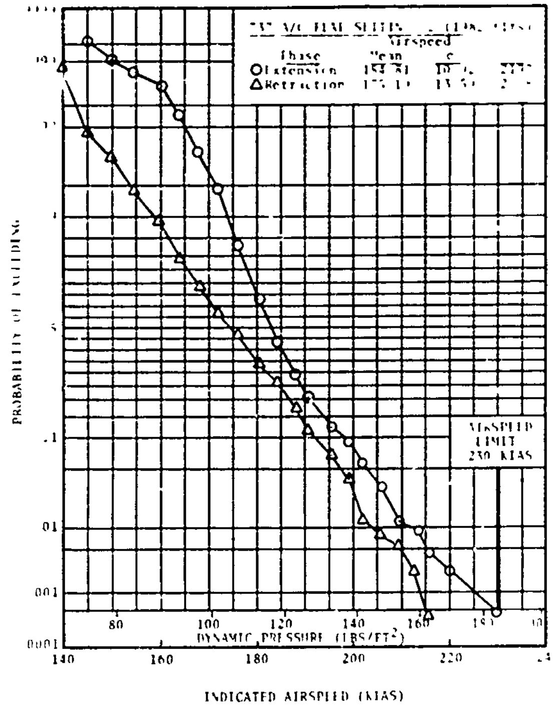


(d) Stabilizer Deflections

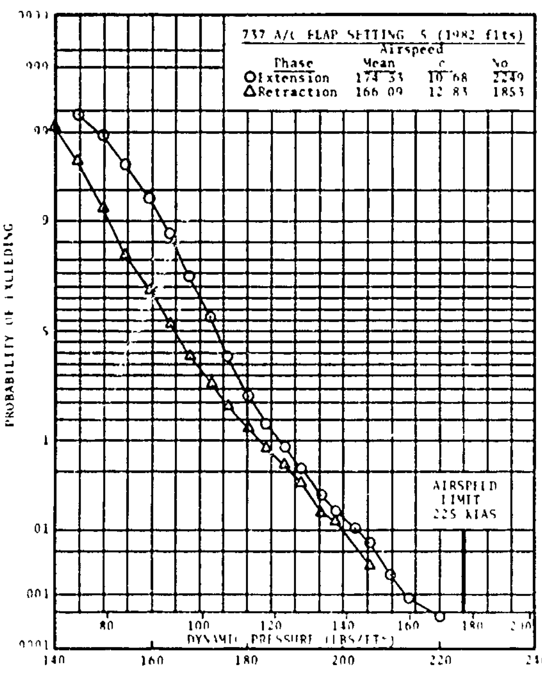
Figure 28 - Concluded



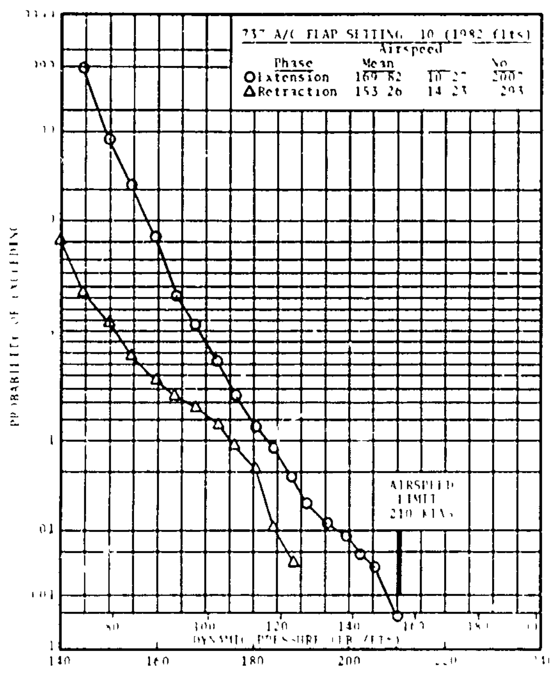
(a) Flap Setting 1°



(b) Flap Setting 2°

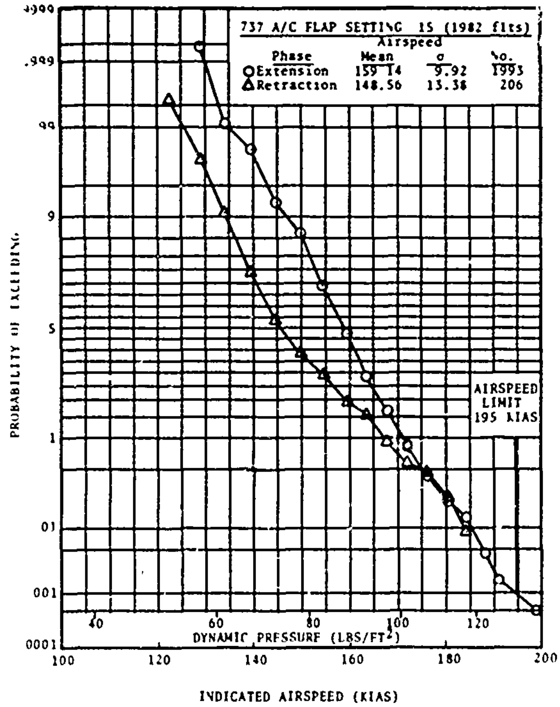


(c) Flap Setting 5°

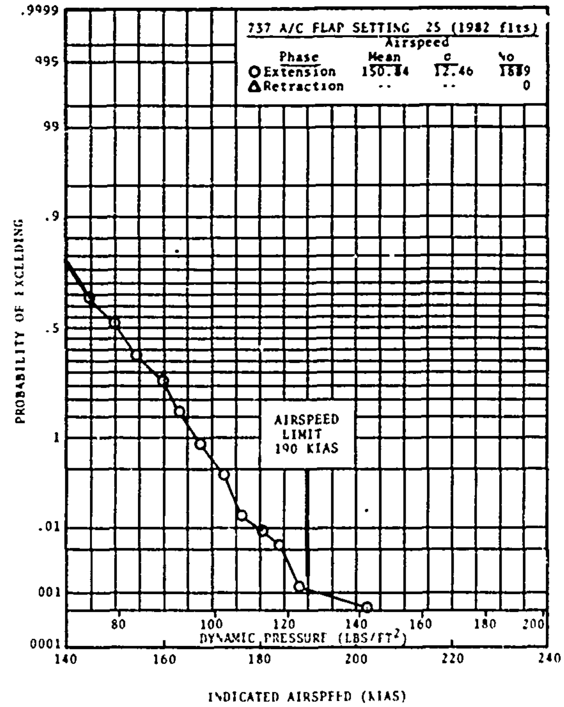


(d) Flap Setting 10°

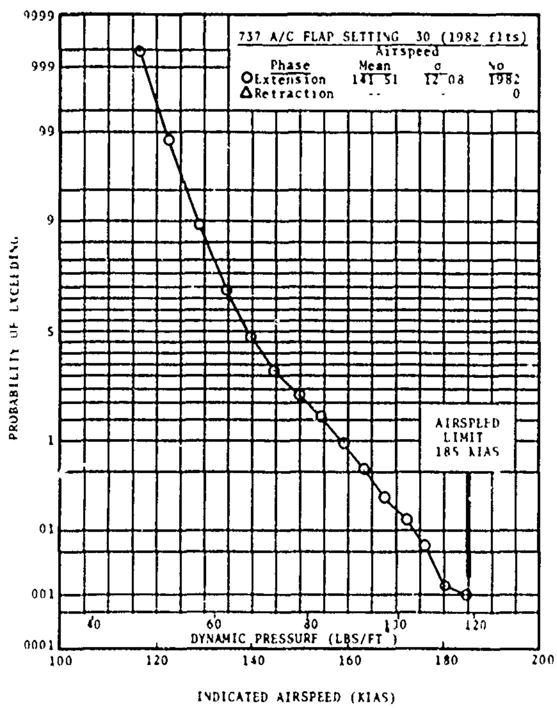
Figure 29. Probability of Exceeding Airspeed and Dynamic Pressure Levels at Eight Flap Settings During Flap Extensions and Retractions



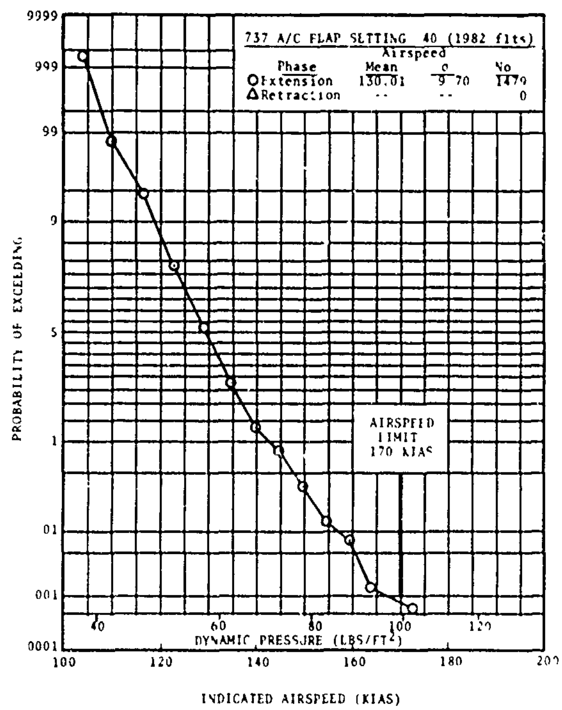
(e) Flap Setting 15°



(f) Flap Setting 25°



(g) Flap Setting 30°



(h) Flap Setting 40°

Figure 29 - Concluded

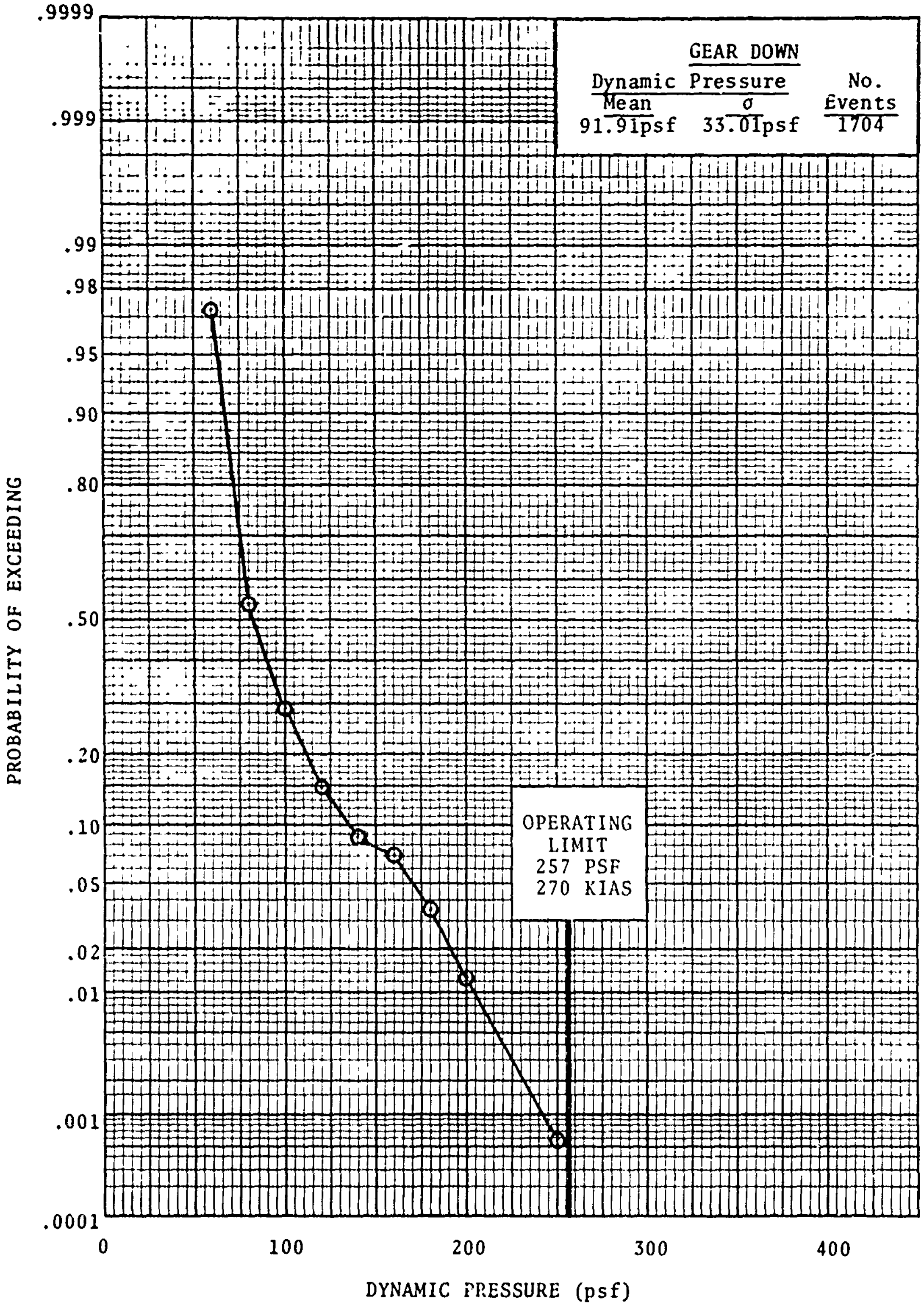


Figure 30. Probability of Exceeding Dynamic Pressure Levels During Landing Gear Extension

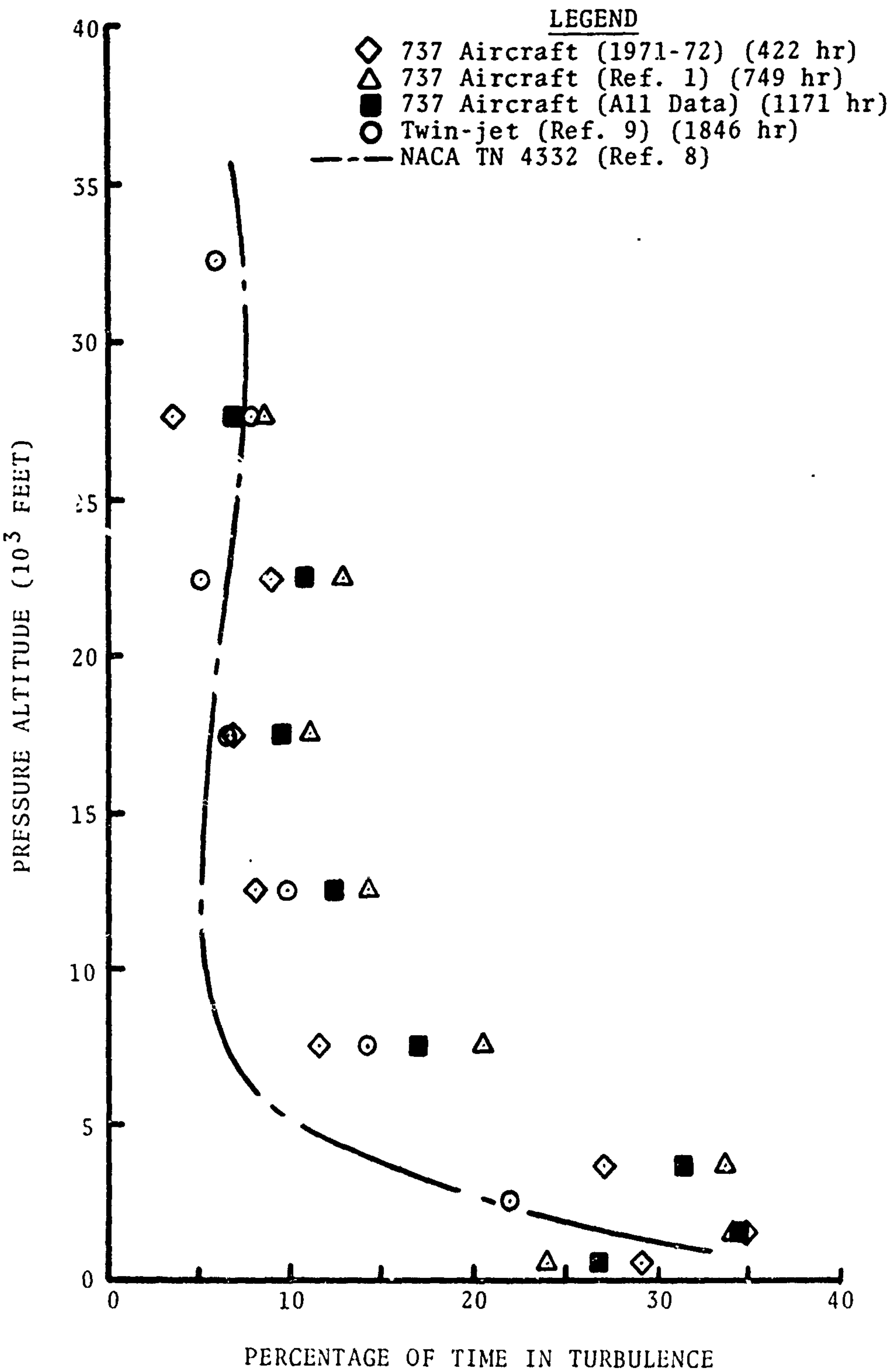


Figure 31. Percentage of Flight Time in Turbulence at Each Altitude Level for 737, a Twin-jet, and NACA TN 4332 Data

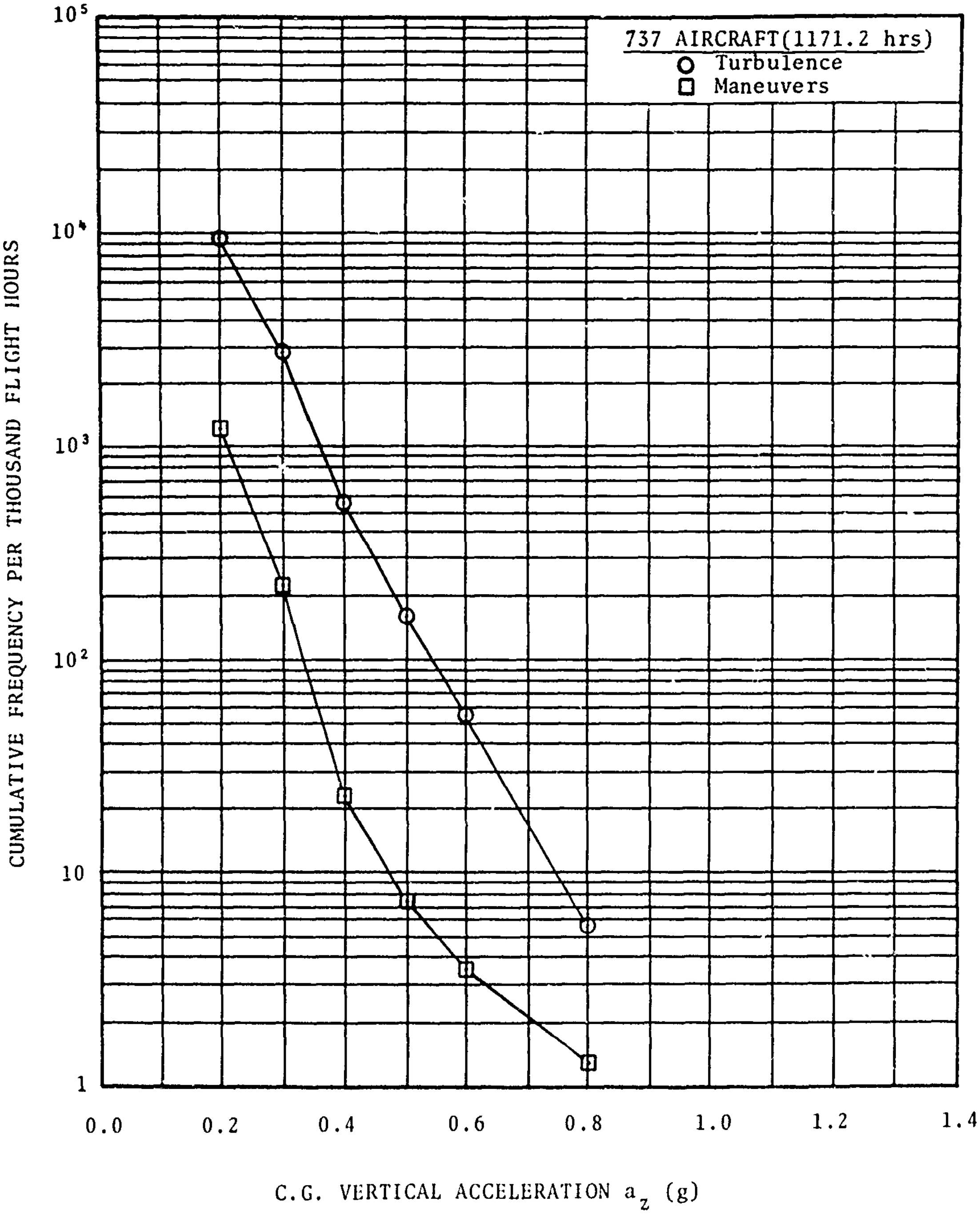


Figure 32. Turbulence and Maneuver Incremental C.G. Vertical Acceleration Peaks per 1000 Flight Hours

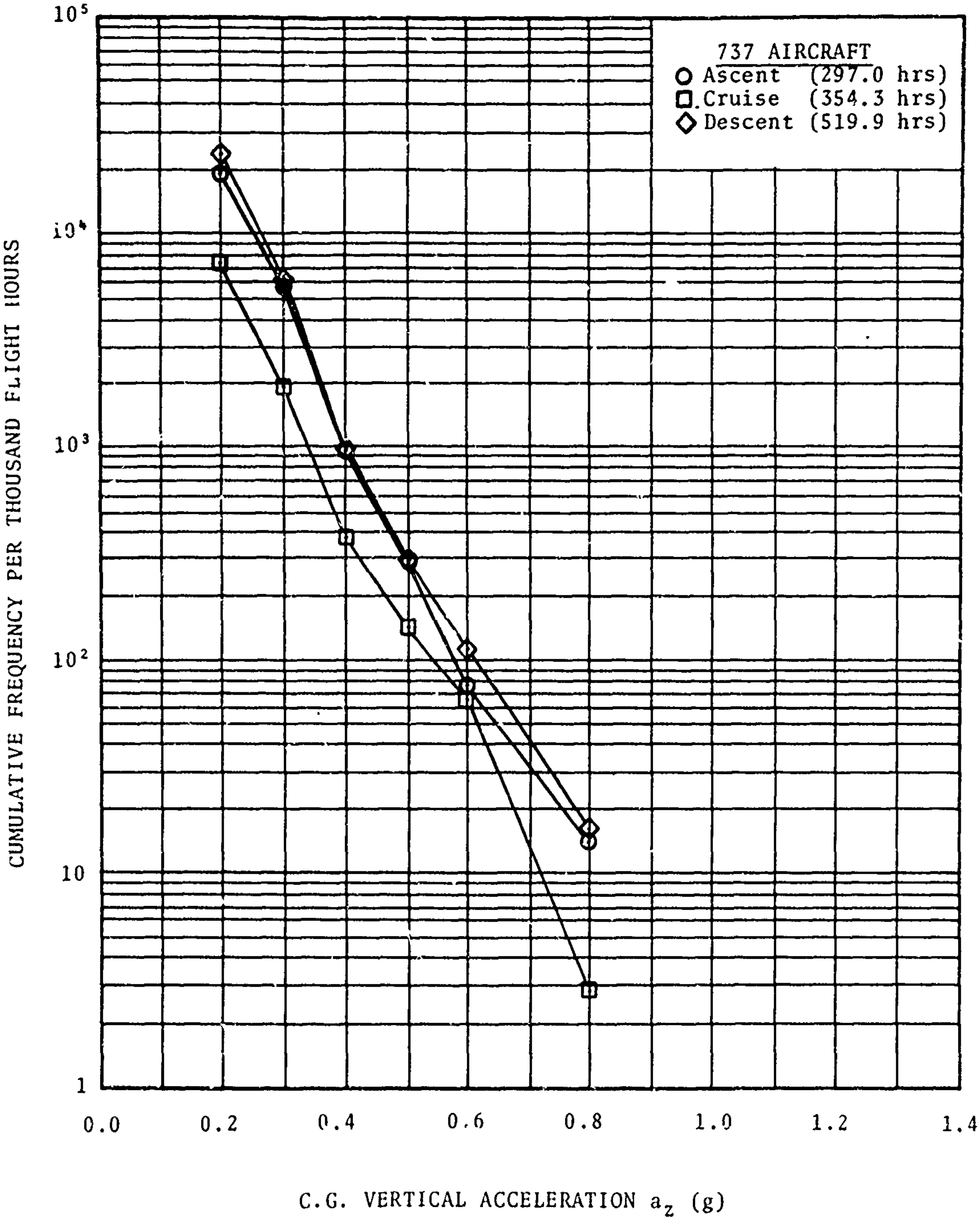


Figure 33. Incremental C.G. Vertical Acceleration Peaks per 1000 Flight Hours in Ascent, Cruise, and Descent

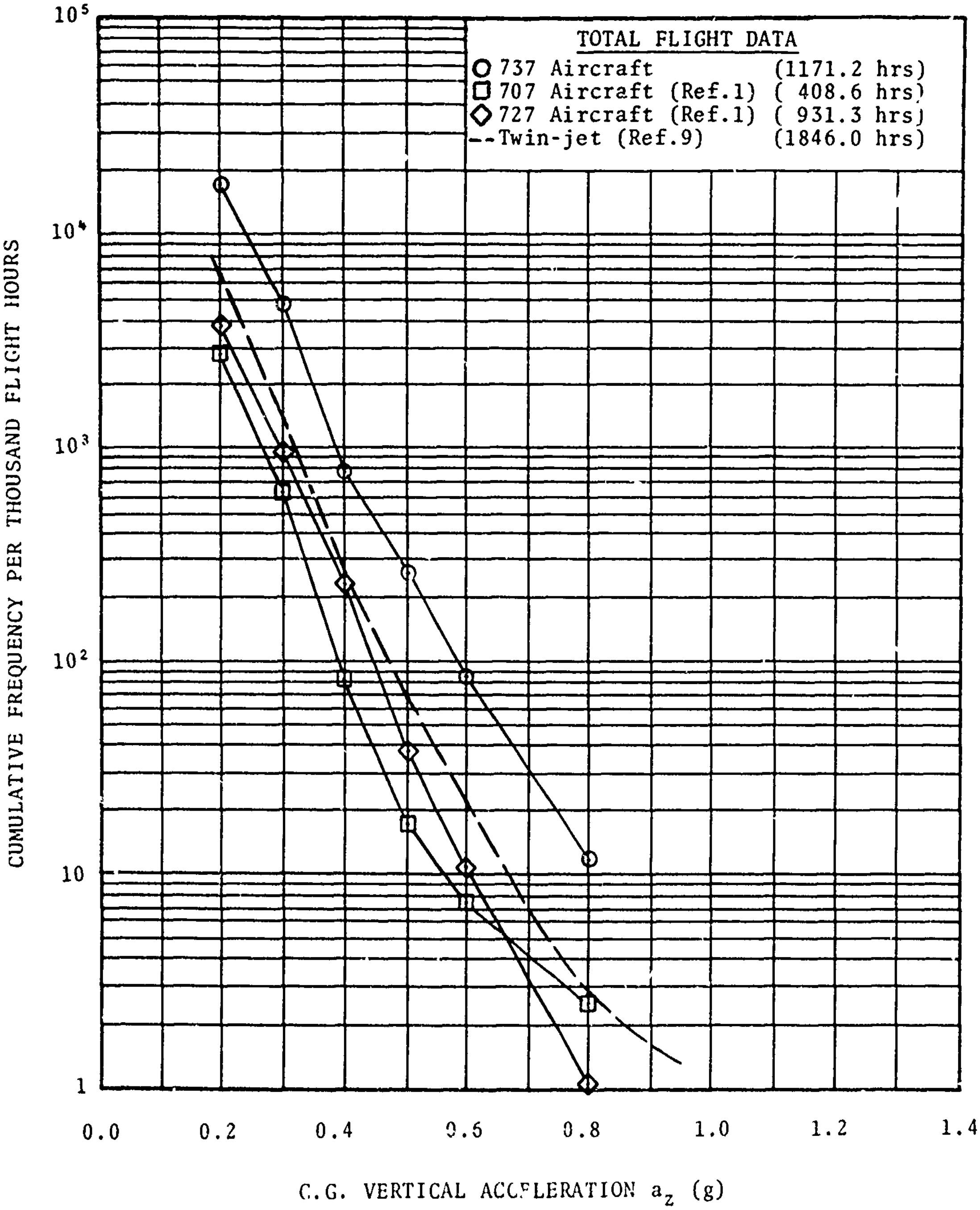


Figure 34. Incremental C.G. Vertical Acceleration Peaks per 1000 Flight Hours for 737 Aircraft and for Reference 9 Twin-jet Aircraft

TABLE 11. DISTRIBUTION OF C.G. VERTICAL ACCELERATION PEAKS IN RANGES OF NORMAL LOAD FACTOR AND INDICATED AIRSPEED

NZ VS VELOCITY

									NZ DISTRIBUTION											
	LESS	-0.5	0.0	0.2	0.4	0.5	0.6	0.7	THRESHOLD	1.2	1.3	1.4	1.5	1.6	.8	2.0	2.5	3.0	TOTAL	HOURS
LESS																				
25																				
50																				
75																				
100								18		343	48	1							410	32.31
125						2	43	158		1008	193	11	1	2					1418	63.64
150				1		4	55	187		866	231	19	4	1					1368	42.05
175					5	13	99	275		1437	487	56	9	1					2382	55.44
200				3	5	22	107	292		1353	413	52	11	9					2267	60.76
225			1	8	21	82	343	715		3656	1254	166	43	21	3				6313	209.30
250			1	9	21	78	261	562		2015	645	132	44	18	3				3789	106.52
275				2	13	36	157	272		1250	436	78	33	16	6				2297	63.80
300			1	3	9	25	97	234		1343	446	59	20	12	2				2251	159.02
325				1	7	19	112	297		1493	413	61	19	9					2431	275.96
350				1	1	6	17	78		365	73	11	1	1	1				555	96.35
375																				0.04
400																				
425																				
450																				
TOTALS			3	28	82	287	1291	3088		15129	4639	646	185	90	13				25481	1171.22

(Note: All ranges are denoted by their lower limits. For example, 0.7 indicates the n_z interval from 0.7 to 0.8g.)

TABLE 12. DISTRIBUTION OF C.G. VERTICAL ACCELERATION PEAKS IN RANGES OF NORMAL LOAD FACTOR AND PRESSURE ALTITUDE

NZ VS ALTITUDE

									NZ DISTRIBUTION											
	LESS	-0.5	0.0	0.2	0.4	0.5	0.6	0.7	THRESHOLD	1.2	1.3	1.4	1.5	1.6	1.8	2.0	2.5	3.0	TOTAL	HOURS
LESS						1	29	141		487	77	5	2	1					743	30.88
1000					3	10	102	339		1729	395	49	9						2636	70.60
2000			1	9	18	93	309	934		4872	1585	205	51	17					8094	195.79
5000			1	7	17	78	362	710		3173	982	140	34	21	3				5528	242.17
10000				11	29	58	308	517		2491	873	165	55	35	10				4552	230.67
15000				1	6	30	87	229		1190	390	37	21	8					1999	166.48
20000					5	6	58	128		630	159	18	5	4					1013	105.85
25000			1		4	10	35	88		477	148	23	6	4					796	122.39
30000						1	1	2		79	30	4	2						119	6.19
35000										1									1	0.21
40000																				
TOTALS			3	28	82	287	1291	3088		15129	4639	646	185	90	13				25481	1171.22

TABLE 13. DISTRIBUTION OF C.G. VERTICAL ACCELERATION PEAKS IN RANGES OF NORMAL LOAD FACTOR AND AIRCRAFT WEIGHT

NZ VS WEIGHT

									NZ DISTRIBUTION											
	LESS	-0.5	0.0	0.2	0.4	0.5	0.6	0.7	THRESHOLD	1.2	1.3	1.4	1.5	1.6	1.8	2.0	2.5	3.0	TOTAL	HOURS
60000							2	5		17	2								26	1.22
70000			1	11	16	69	223	438		2161	642	116	22	14	2				3715	122.12
80000			1	14	43	145	729	1700		9167	2857	377	114	53	8				15203	696.21
90000			1	3	23	73	333	941		3710	112	153	48	23	3				6440	342.71
100000							4	4		74	1		1						97	8.96
110000																				
120000																				
130000																				
140000																				
150000																				
160000																				
170000																				
180000																				
190000																				
200000																				
210000																				
220000																				
230000																				
240000																				
250000																				
260000																				
TOTALS			3	28	82	287	1291	3088		15129	4639	646	185	90	13				25481	1171.22

TABLE 14. DISTRIBUTION OF C.G. VERTICAL ACCELERATION PEAKS IN NORMAL LOAD FACTOR RANGES AND PHASES

NZ VS PHASE

NZ DISTRIBUTION

	LESS	-0.5	0.0	0.2	0.4	0.5	0.6	0.7	THRESHOLD	1.2	1.3	1.4	1.5	1.6	1.8	2.0	2.5	3.0	TOTAL	HOURS
TAKOFF				1	3	25	212	877		2632	777	114	27	4					4472	55.48
ASCENT			1	7	23	98	479	1129		4101	1414	192	61	19	4				7527	297.04
CRUISE				3	17	49	[illegible]	417		1859	553	86	26	22	1				3217	354.30
DESCNT			2	18	42	140	628	1543		9169	2672	363	98	49	8				14737	519.89
LANDNG				3	11	58	429	1356		6806	2943	773	259	197	29	7			12871	45.89
TOTALS			3	32	96	370	1932	5321		24567	8359	1533	471	291	42	7			43024	1272.59

TABLE 15. DISTRIBUTION OF C.G. VERTICAL ACCELERATION PEAKS IN RANGES OF NORMAL LOAD FACTOR AND PRESSURE ALTITUDE FOR SMOOTH AIR AND TURBULENCE

(a) By Altitude Interval

ALTITUDE LESS

NZ DISTRIBUTION

	LESS	-0.5	0.0	0.2	0.4	0.5	0.6	0.7	THRESHOLD	1.2	1.3	1.4	1.5	1.6	1.8	2.0	2.5	3.0	TOTAL	HOURS
SMOOTH AIR							2	27		132	23	3							187	22.60
TURBULENCE						1	27	114		355	54	2	2	1					556	8.28
TOTALS						1	29	141		487	77	5	2	1					743	30.85

ALTITUDE 1000

NZ DISTRIBUTION

	LESS	-0.5	0.0	0.2	0.4	0.5	0.6	0.7	THRESHOLD	1.2	1.3	1.4	1.5	1.6	1.8	2.0	2.5	3.0	TOTAL	HOURS
SMOOTH AIR							9	40		322	57	4							432	46.33
TURBULENCE					3	10	93	299		1407	338	45	9						2204	24.27
TOTALS					3	10	102	339		1729	395	49	9						2636	70.60

ALTITUDE 2000

NZ DISTRIBUTION

	LESS	-0.5	0.0	0.2	0.4	0.5	0.6	0.7	THRESHOLD	1.2	1.3	1.4	1.5	1.6	1.8	2.0	2.5	3.0	TOTAL	HOURS
SMOOTH AIR							3	47		562	118	4	1						735	134.37
TURBULENCE			1	9	18	93	306	887		4310	1467	201	50	17					7359	61.42
TOTALS			1	9	18	93	309	934		4872	1585	205	51	17					8094	195.79

ALTITUDE 5000

NZ DISTRIBUTION

	LESS	-0.5	0.0	0.2	0.4	0.5	0.6	0.7	THRESHOLD	1.2	1.3	1.4	1.5	1.6	1.8	2.0	2.5	3.0	TOTAL	HOURS
SMOOTH AIR						2	8	50		435	70	5							570	201.04
TURBULENCE			1	7	17	76	354	660		2738	912	135	34	21	3				4958	41.14
TOTALS			1	7	17	78	362	710		3173	982	140	34	21	3				5528	242.17

ALTITUDE 10000

NZ DISTRIBUTION

	LESS	-0.5	0.0	0.2	0.4	0.5	0.6	0.7	THRESHOLD	1.2	1.3	1.4	1.5	1.6	1.8	2.0	2.5	3.0	TOTAL	HOURS
SMOOTH AIR				3	1	5	15	37		370	84	7	4	2	3				531	201.92
TURBULENCE				8	28	53	293	480		2121	789	158	51	33	7				4021	28.75
TOTALS				11	29	58	308	517		2491	873	165	55	35	10				4552	230.67

ALTITUDE 15000

NZ DISTRIBUTION

	LESS	-0.5	0.0	0.2	0.4	0.5	0.6	0.7	THRESHOLD	1.2	1.3	1.4	1.5	1.6	1.8	2.0	2.5	3.0	TOTAL	HOURS
SMOOTH AIR						2	7	22		152	21	2	1						207	150.89
TURBULENCE				1	6	28	80	207		1038	369	35	20	8					1792	15.60
TOTALS				1	6	30	87	229		1190	390	37	21	8					1999	166.48

TABLE 15 - Concluded

ALTITUDE [illegible]

	[illegible]	TOTAL	HOURS
SMOOTH AIR	[illegible]	[illegible]	[illegible]
TURBULENCE	[illegible]	[illegible]	[illegible]
TOTALS	[illegible]	[illegible]	[illegible]

ALTITUDE [illegible]

	[illegible]	TOTAL	HOURS
SMOOTH AIR	[illegible]	[illegible]	[illegible]
TURBULENCE	[illegible]	[illegible]	[illegible]
TOTALS	[illegible]	[illegible]	[illegible]

ALTITUDE [illegible]

	[illegible]	TOTAL	HOURS
SMOOTH AIR	[illegible]	[illegible]	[illegible]
TURBULENCE	[illegible]	[illegible]	[illegible]
TOTALS	[illegible]	[illegible]	[illegible]

ALTITUDE [illegible]

	[illegible]	TOTAL	HOURS
SMOOTH AIR	[illegible]	[illegible]	[illegible]
TURBULENCE	[illegible]	[illegible]	[illegible]
TOTALS	[illegible]	[illegible]	[illegible]

(b) Summation of All Altitudes

	[illegible]	TOTAL	HOURS
SMOOTH AIR	[illegible]	[illegible]	[illegible]
TURBULENCE	[illegible]	[illegible]	[illegible]
TOTALS	[illegible]	[illegible]	[illegible]

APPENDIX II

UERS DESCRIPTION

This appendix briefly describes the recorder, the tape magazine, the signal conditioning unit, the transducers, and the calibration of the equipment.

A. DARS RECORDER

The UERS system was designed around a Conrac Digital Adaptive Recording Set (DARS) recorder. The DARS recorder is an airborne 24-channel digital magnetic tape recorder. As viewed in Figure 35, the recorder is 16 inches wide, 13 inches deep, and 6 inches high; it weighs 29 pounds. The standard 115 volt, 400 Hz ac, and 28 volt dc aircraft power sources operated the recorder. Each of the channels is designed to accept 0- to 5-volt dc analog input signals The block diagram in Figure 36 depicts the basic functional arrangement of the major components in the recorder. As indicated, the inputs to each channel are sampled by a multiplexer circuit, digitized by an analog-to-digital converter, placed in a temporary storage for data compression, routed through a formatter for time identification, entered in either of two buffer memories where the parity bit is generated, and finally directed to the tape magazine f r permanent recording.

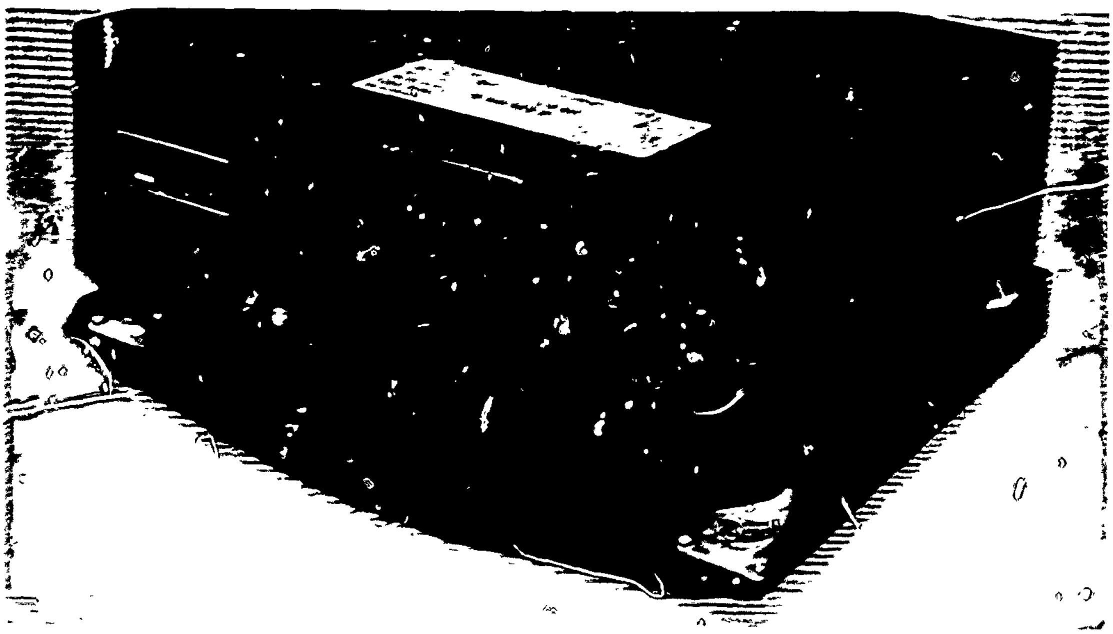


Figure 35. View of DARS Recorder

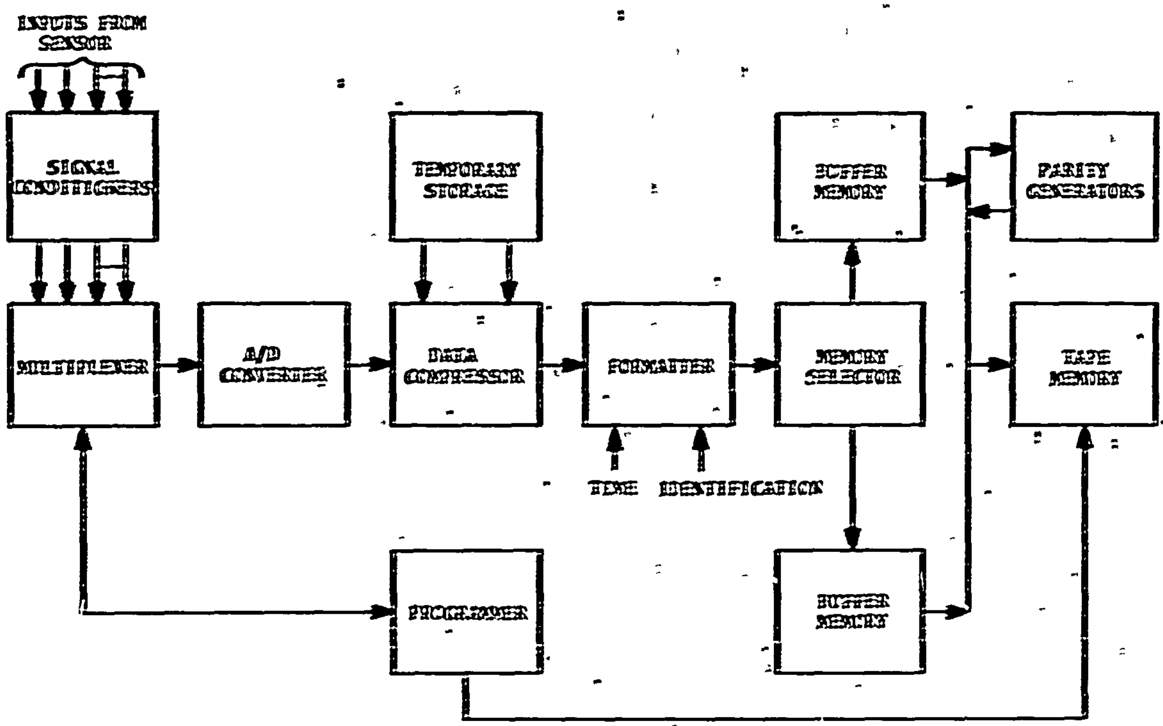


Figure 36. Functional Block Diagram of Major Components in DARS Recorder

The main feature of the DARS recorder is its capability of so sampling the data that only significant parameter changes are selected for data recording. As a result, redundant data, such as recorded during aircraft cruise when the flight parameters are virtually constant, is eliminated, and the tape capacity is used more effectively. When conventional digital magnetic tape recorders are employed, the redundant data may be discarded only during the subsequent computer processing of the recorded data. Figure 37 illustrates the effectiveness of the DARS data compression. As seen here where the digital levels and a trace of a typical analog signal are drawn, the DARS recorder with its data compression feature retains only the significant data, a fraction of the data taken by a recorder without this feature.

Since the DARS has the capability of taking a total of 240 samples per second, the sampling rate for each channel was selected according to the anticipated frequency of the parameter changes. For example, stabilizer position, on Channel 18, was sampled only twice a second since it changes very slowly, whereas bank angle (roll), on Channel 11, was sampled ten times a second since it fluctuates more frequently.

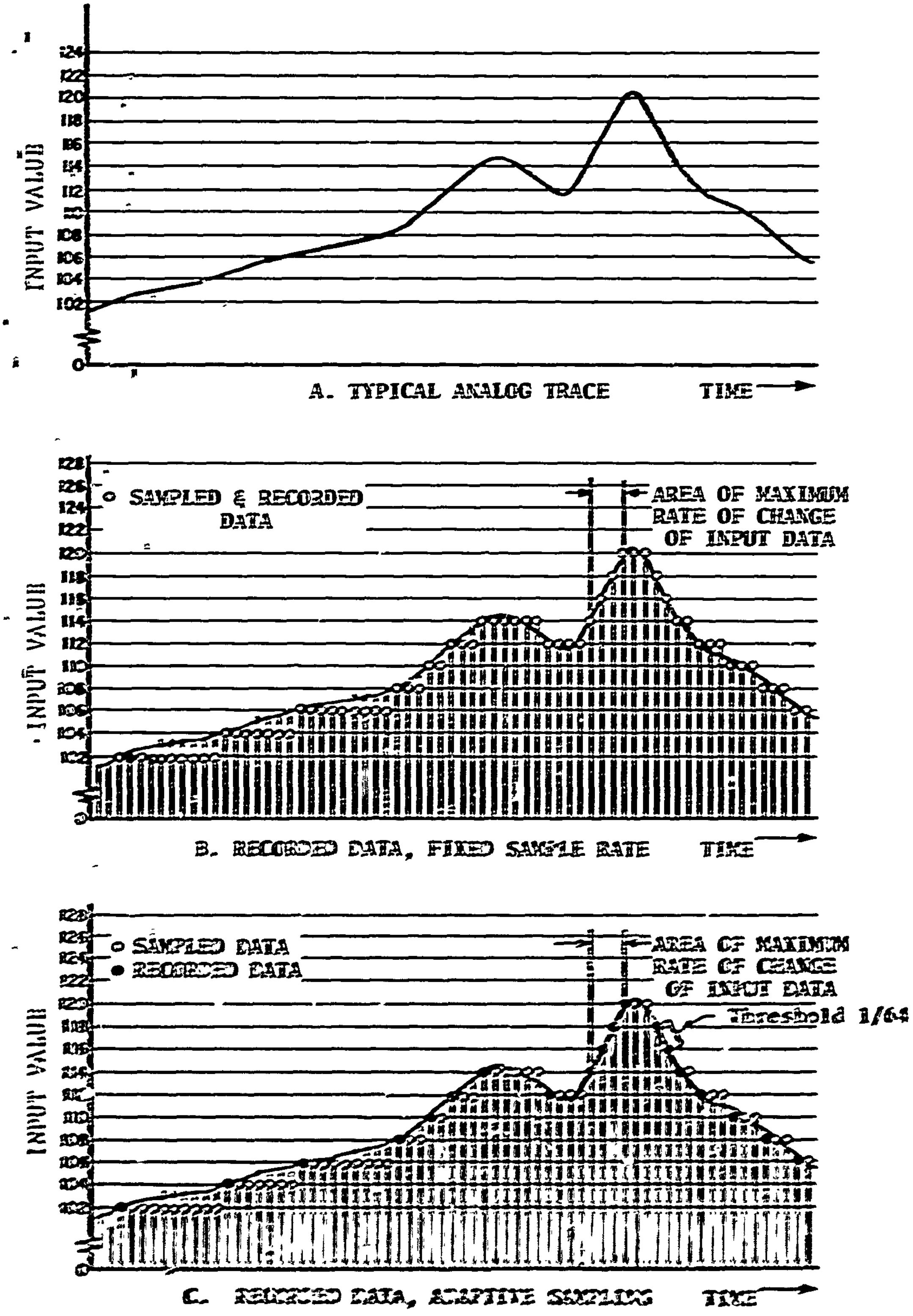


Figure 37. Illustration of [illegible] Data Compression

The data compression requires a comparison of each digitized data sample with the last recorded value for the same channel. If the two values differ by more than a "threshold" value, the new value is stored in one of the two buffer memories; if their difference is less than the threshold, the new value is discarded. Since a certain amount of low-level "noise" is present in each parameter, the threshold value can be chosen to eliminate the noise but retain all significant parameter variations. Although the threshold values vary from channel to channel, they are fixed by the recorder design. The threshold values for each channel of the UERS recorders are 1/128, 1/64, or 1/32 of full scale (5 volts).

As each new value is stored in the buffer memory, the time and the channel identification are added to it to form one digital word in three-character form. When a buffer memory has been filled to capacity, the memory selector shifts to the other buffer memory, the magazine tape drive (inactive since the last buffer memory filling) is started, and the data in the filled buffer memory is recorded on the tape. After the data has been recorded, the tape drive stops and the buffer is erased.

Table 16 lists the channel numbers and their corresponding parameter identification, sampling rate, parameter range, threshold, and estimated measurement accuracy for the UERS system in the 737 aircraft.

TABLE 16. CHANNEL NO., SAMPLING RATE, RANGE, THRESHOLD, AND ACCURACY FOR EACH RECORDED PARAMETER

Channel	Parameter	Sampling Rate	Range	Threshold	Accuracy
1	Elevator	2	Full up to full down	1/64	2.8%
2	Fuel	2	0 to 19,000 pounds	1/64	5.4%
3	RPM1	1	0 to 110% of full RPM	1/32	5.4%
4	Taxi	2	0 to 65 knots	1/64	3.4%
5	C.G. N_z	50	+3.5 to -1.5	1/64	1.7%
6	Flaps	2	Full up to full down	1/32	2.8%
**7	DME, Main Wheel Squat	50	See Note 2	1/64	1.7%
8	Cockpit N_y	50	+1 to -1	1/64	1.7%
9	Time Base & VOR	20	108 to 117.9 MHz	1/128	N/A
10	RPM2	2	0 to 110% of full RPM	1/32	5.4%
11	Roll	10	+90° to -90°	1/64	2.4%
12	Pitch	10	+45° to -45°	1/64	2.4%
13	Altitude	10	0 to 45,000 feet	1/128	1.7%
14	Heading	10	0 to 360°	1/64	1.7%
15	Airspeed Low	10	0 to 200 knots	1/64	2.8%
16	Airspeed High	10	0 to 450 knots	1/64	1.7%
*17	Digital Switches	2	See Note 1	1/64	N/A
18	Stabilizer	2	Full up to full down	1/64	1.7%
19	Localizer Deviation	10	-208 to +208 µamps	1/128	3.3%
**20	Aileron, Wheel Brakes	2	Full right to full left	1/32	1.7%
21	C.G. N_y	50	+1 to -1	1/64	1.7%
22	Markers	1	Indication only	1/32	N/A
23	Rudder	2	Full right to full left	1/64	2.8%
24	Glide Slope Deviation	10	-208 to +208 µamps	1/128	3.3%

Note 1
*Speed Brake
Landing Gear
Auto-Pilot Roll
Auto-Pilot Pitch
Alt-Hold
Yaw Damper

Note 2
DME Range 0 to 199 Miles
This measurement discontinued early in the program.

Note 3
Accuracy is [illegible] of full scale for a change of temperature of [illegible]

**Note 4
[illegible]

The DME data was initially recorded to permit computing the distance to threshold. However, the recording of this data was terminated early in the program because only a few airports with ILS systems were also equipped with DME facilities. Also contributing to the decision for this termination was the fact that this parameter required a large amount of recording tape to achieve the desired accuracy.

B. DARS TAPE MAGAZINE

The DARS tape magazine is a hermetically sealed plug-in cartridge containing all the record heads, drive mechanism, and electronics needed to record the data. The magazine contains 600 feet of one-half-inch magnetic tape. A counter on the magazine indicates the percentage of remaining tape. Easily inserted into and removed from the DARS recorder, the magazine was designed to withstand the high accelerations and temperature of crash environments. As viewed in Figure 35, the magazine is 7 inches wide, 7 inches long, and 4.5 inches high; it weighs 12 pounds. The DARS recorder supplies all power needed for the tape drive and the start, stop, and record signals.

C. UERS SIGNAL CONDITIONER

Technology Incorporated designed and fabricated a signal conditioning unit for the UERS system. The unit receives and reforms transducer signals and aircraft pickup signals so that they will be compatible with the DARS recorder data channels. The packaged unit is 7-1/2 inches high, 7-1/2 inches wide, and 20 inches long; weighs about 20 pounds; and fits in a standard 3/4 ATR rack in the aircraft electronics bay.

D. TRANSDUCERS

The UERS system required several types of transducers. The types may be generally grouped into two categories: the aircraft transducers which are an integral part of the aircraft instruments and the additional transducers which were installed with the UERS.

1. Aircraft Transducers

Wherever possible, existing transducers in the aircraft system were tapped to acquire signals for the parameters to be recorded in the UERS system. Some signals, such as those for DME and flap position, are in the form of synchro stator information. Others, such as those for VOR frequency, autopilot mode, wheel brakes, gear up, and gear touchdown, are in the form of switching levels which provide ground or voltage level signals to indicate the mode of a switch position. Engine speed is monitored by sampling the tachometer generators that produce frequencies proportional to engine N2 rpm.

2. UERS Transducers

The various types of additional transducers were cable position transducers to measure control surface deflections, accelerometers placed at the center of gravity and beneath the cockpit to measure vertical and lateral acceleration, pressure transducers to sense static and pitot pressures, and probe transducers mounted through the fuselage skin to measure angle of attack, angle of sideslip, and total outside air temperature.

E. UERS SYSTEM CALIBRATION

The UERS system was initially calibrated in the contractor's instrument laboratory and during the installation, and interim checks were performed during the recording period. A final calibration was also performed at the completion of the recording period. The accelerometers and pressure transducers were calibrated under static conditions with laboratory instruments to derive their calibration curves and scale factors. Those transducers which used part of the aircraft instruments were calibrated, wherever possible, by using the aircraft's instruments or maintenance equipment. Extreme care was taken in obtaining the calibration for the glide slope and localizer parameters. To obtain values of these parameters more accurate than the readouts of the aircraft's flight director, a precision digital voltmeter was used to measure the current through this instrument, and the measurements were cross-referenced with the readouts during the calibration. The operation of the navigation receiver was simulated by removing the receiver and inserting a constant current source to drive the aircraft system.

The taxi speed transducer was the only sensor which required using the manufacturer's calibrations. Frequencies proportional to ground speed were obtained from the manufacturer of the transducer to determine the calibration curve for this parameter. Because of inherent signals within the anti-skid system, only speeds up to 65 knots were measured.

A set of initial calibrations were performed during the assembly and installation of the 737 UERS system in October and November 1971. In addition to normal calibration checks conducted during the program, a complete set of final calibrations were performed during removal of the 737 UERS system in May 1972. For each channel, Table 17 lists the output slopes determined during the initial and final calibrations.

TABLE 17. INITIAL AND FINAL CALIBRATION DATA FOR THE UERS SYSTEM IN THE 737 AIRCRAFT

Channel No.	Parameter	Units	Range	Initial Calibration Slope (per count)	Final Calibration Slope (per count)
1	Elevator	% Full Aft	Fwd to Aft	-1.88	-2.10
2	Fuel Quan.	Lb.	0 to 19,000	218.4	218.4
3	RPM - No. 1	Percent	0 to 110	0.89	0.89
4	Taxi Speed	Knots	0 to 65	0.71	0.69
5	C.G. n_z	g	-1.5 to 3.5	0.041	0.041
6	Flaps	See Note No. 1		-	-
7	DME	Miles	0 to 10	0.079	0.079
8	Cockpit n_y	g	-1.0 to 1.0	0.016	0.016
9	VOR Freq.	MHZ	108.0 to 117.9	0.079	0.079
10	RPM - No. 2	Percent	0 to 110	0.88	0.88
11	Roll Angle	Degrees	-90 to 90	1.42	1.42
12	Pitch Angle	Degrees	-45 to 45	-0.70	-0.70
13	Altitude	In. Hg.	4 to 31	0.256	0.259
14	Heading	Degrees	0 to 360	-2.81	-2.81
15	Airspeed Low	In. Hg.	0 to 2	0.0154	0.0162
16	Airspeed High	In. Hg.	0 to 9	0.0725	0.0705
17	Events	See Note No. 2		-	-
18	Stabilizer	% Full Travel	Nose Dn to Nose Up	2.00	2.36
19	Localizer	Micro-amps	-200 to 200	3.23	3.85
20	Aileron	% Full Right	Lt to Rt	2.20	2.68
21	C.G. n_y	g	-1.0 to 1.0	0.0164	0.0166
22	Markers	-	Off,OM,MM	-	-
23	Rudder	% Full Right	Lt to Rt	2.44	2.44
24	Glide Slope	Micro-amps	-150 to -150	2.50	2.50

Note No. 1) Flap Position:

Flap Position	Output-Initial Calibration	Output-Final Calibration
Up	12[illegible] Counts	1[illegible]6 Counts
1	105 "	108 "
2	90 "	90 "
5	69 "	69 "
10	54 "	53 "
15	40 "	40 "
25	27 "	27 "
30	14 "	15 "
40	0 "	0 "

Note No. 2* Digital Switch Functions.

Digital Switch Functions	Output* Initial Calibration	Output* Final Calibration
Autopilot Pitch Mode	[illegible] Counts	-6 Counts
Autopilot Altitude Hold	-16 "	-23 "
Yaw Damper On	[illegible] "	-8 "
Landing Gear Down	[illegible] "	-32 "
Ground Spoilers Up	42 "	-42 "

*Each switch function causes an incremental output change. Return of the function to its off position causes an equal output change in the opposite direction.

APPENDIX III

DATA PROCESSING PROCEDURES AND DATA DEFINITIONS

This appendix describes the computer interface and the data processing procedures while defining the data categories and parameters.

A. DARS PLAYBACK INTERFACE

Although the data on a DARS magazine tape is in a standard computer format, the data cannot be directly transferred to a conventional computer because the shape and the drive mechanism of the hermetically sealed unit are not compatible with standard tape transports. Accordingly, Technology Incorporated designed and constructed a computer interface which along with peripheral adapters interfaces the tape magazine with the Company's Honeywell Model 1015 computer. The interface contains the electronics to drive the tape, to sense the start and end of the tape data, to perform the parity check and thereby discard erroneous data, and to transcribe the original data into the computer memory. Then the interface erases the magazine tape for reuse, and the computer transfers the data from memory to a tape on one of its standard tape transports.

B. UNUSUAL EVENTS DATA

Preparatory to reviewing the UERS data for unusual events, the computer printed out a listing of the data for each channel in successive 10-minute segments of recorded operation. This listing was visually scanned for parameter patterns indicative of unusual events and for parameter values reflecting the proper operation of the recording system. No unusual events (as defined at the start of the program) were encountered.

C. STATISTICAL DATA

1. Introduction

During the data processing, several types of statistical information were extracted from the recorded data. Since the different types of statistical information required different variables and data categories, these types were treated separately during the data processing.

Because only three of the recorded variables were required, the data was first processed for VGH data which includes distributions of c.g. vertical acceleration peak values and elapsed time in intervals of airspeed, altitude, and gross weight. Then, with flight segments and other information from the VGH data, all suitable recorded data was processed for Normal Events data, as defined below. As noted during this processing, those recorded flights with ILS approaches were selected and processed for ILS

Preceding page blank

data which comprises glide slope and localizer needle deviations at specified points during each approach. Finally the recorded ground data was processed for Taxi data, including vertical and lateral acceleration peaks, time in taxi speed intervals, and lateral acceleration during turns; and the recorded flight data was processed to obtain airspeeds at each flap setting during flap extensions and retractions.

The procedures and definitions required for processing each of the above types of data are described in the following paragraphs.

2. VGH Data

a. VGH Definitions

The extraction of VGH data from the recorded UERS data was based on the detection of c.g. normal acceleration peaks according to the following criteria:

An acceleration peak (or trough) was defined as any maximum (or minimum) incremental acceleration value above 0.2g (or below -0.2g) preceded and followed by a rise and decay each half the peak value and at least 0.2g closer to 0.0g. The normal acceleration values a_z were converted to normal load factors n_z by the relation $n_z = (a_z/g) + 1.0$, where g is the acceleration due to gravity.

b. Turbulence

Turbulence was defined as a period of continuous c.g. normal acceleration activity with a duration of at least 1.0 minute. During this period at least one 0.25-minute section had to have nine or more crossings of the 0.0g level and every 0.25-minute section had to have at least two crossings of this level. If two turbulence periods were separated by less than a minute of smooth air, they were classified as a single continuous turbulence period.

3. Normal Events Data

a. Normal Event Definitions

To meet the expanded data objectives listed in the Introduction, 37 normal events were selected to define the aircraft operation for each flight. During the data processing, the set of data representing these events was called the "Normal Events Data." The definitions of these events, listed in Table 18, were such that some events occurred once in each flight, some occurred several times in a flight, and some did not occur at all in many flights. The liftoff and touchdown of each flight were identified by visually scanning a computer listing of the values for 12 parameters recorded during the first and last 2

TABLE 18. CODE NUMBERS, TITLES, AND DEFINITIONS FOR 37 NORMAL EVENTS

Code No.	Title	Definition
1	Recorder Power On	Immediately following automatic recorder self-test
2	Rotation	Pitch angle increase of 3° before liftoff
3	Liftoff	Identified manually from activity of c.g. vertical acceleration
4	Gear Up	Recorded event in data channel 17
5	Not Used	
6	Liftoff + 120 Seconds	Identified by time from liftoff
7	Not Used	
8	Outer Marker	Midpoint of recorded outer marker indicator lamp flashes
9	Flaps Up	First zero flap setting recorded on channel 6
10	Begin Cruise	Identified manually from airspeed and altitude profiles
11	Begin Descent	Identified manually from airspeed and altitude profiles
12	Gear Down	Recorded event in data channel 17
13	Touchdown -180 seconds	Identified by time from touchdown
14	Touchdown -150 seconds	Identified by time from touchdown
15	Touchdown -120 seconds	Identified by time from touchdown
16	Touchdown -90 seconds	Identified by time from touchdown
17	Touchdown -60 seconds	Identified by time from touchdown
18	Touchdown -40 seconds	Identified by time from touchdown
19	Touchdown -20 seconds	Identified by time from touchdown
20	Touchdown -10 seconds	Identified by time from touchdown
21	Touchdown -5 seconds	Identified by time from touchdown
22	Middle Marker	Midpoint of recorded middle marker indicator lamp flashes
23	Touchdown -2 seconds	Identified by time from touchdown
24	Touchdown -1 second	Identified by time from touchdown
25	Touchdown	Identified from wheel spin-up on taxi speed channel 4
26	Ground Spoilers	Recorded event in data channel 17 after touchdown
27	Thrust Reverse	8 percent RPM increase after touchdown
28	Taxi Wheel Brakes	Recorded event in data channel 20 during ground operation
29	Landing Wheel Brakes	First recorded event in data channel 20 after touchdown
30	Minimum f_x	Most extreme value for takeoff, climb, cruise, descent and final approach*
31	Maximum f_x	-
32	Minimum f_a	-
33	Maximum f_a	-
34	Minimum f_s	-
35	Maximum f_s	-
36	Minimum f_z	-
37	Maximum f_z	-

*Phase [illegible] includes times from liftoff to liftoff + 2 minutes and final approach includes times from touchdown [illegible] minutes to touchdown.

minutes of the flight. The data recorded at each normal event in each flight was reduced to values for 24 parameters. Table 19 lists the 24 parameters monitored or computed for each event. Some or all of the parameter values for a specific event were eliminated if erroneous data recording caused them to be processed incorrectly.

TABLE 19. TWENTY-FOUR PARAMETERS USED FOR NORMAL EVENTS DATA

Aircraft Weight	Flap Setting
Flight Phase Code	Roll (Bank Angle)
Airport (Arrival & Departure) Code	Pitch Angle
Runway (Arrival & Departure) Code	Heading
Flight Rule Code	VOR Frequency
Wind Factor Code	Rudder Control Deflection
C.G. Vertical Acceleration	Elevator Control Deflection
Taxi Speed	Aileron Control Deflection
Pressure Altitude	Stabilizer Control Deflection
Indicated Airspeed	Autopilot Mode Code
Dynamic Pressure	Engine N_2 Rpm
Stall Margin	Time from Touchdown

b. <u>Flight Phase</u>

Each processed flight was divided into phases according to the criteria in Table 20. As noted in this table, the flight data between liftoff and touchdown was divided into three phases: ascent, cruise, and descent; and the ground data was divided into four phases: preflight taxi, takeoff, landing, and postflight taxi.

Many short flights, particularly for the 737 aircraft, did not have a cruise phase as defined in this table.

c. <u>Autopilot Modes</u>

The various combinations of autopilot settings could produce many autopilot modes. On the basis of normal operational procedures, however, the five listed in Table 21 were selected to describe the autopilot operation in the Events data.

TABLE 20. FLIGHT PHASE DEFINITIONS

FLIGHT PHASE DEFINITIONS

Phase	Definition
Preflight Taxi	Taxi data before initiating takeoff roll
Takeoff	Ground data during takeoff roll
Ascent	Flight data between liftoff and start of cruise
Cruise	Flight data during steady airspeed and altitude conditions. Includes minor ascents and descents between two extended cruise segments
Descent	Flight data between end of cruise and touchdown
Landing	Ground data during touchdown and landing rollout
Post Flight Taxi	Taxi data following turnoff from landing runway

TABLE 21. AUTOPILOT MODES AND CODE NUMBERS

Code No.	Mode
1	Off
2	Yaw damper only
3	Yaw damper and roll-hold
4	Yaw damper and roll- and pitch-hold
5	Yaw damper, roll- and pitch-hold, and altitude-hold

d. Airspeed and Dynamic Pressure

The differential pressure sensed by the aircraft pitot-static system was monitored and converted to indicated airspeed during the data processing. Since available pitot-static position error data for the instrumented aircraft indicated that the difference between indicated and calibrated airspeeds during arrivals and departures would not exceed 2 knots, indicated airspeed was used in the data processing. In the lower airspeed ranges, the pitot-static differential pressure is equal to the free-stream dynamic pressure; and in the high subsonic speed range,

it is equal to the impact pressure, or the so-called "compressible dynamic pressure." Since most of the dynamic pressures in the reported data are in the lower Mach ranges, the pitot-static differential pressure was simply converted to units of pounds per square foot and called "dynamic pressure."

e. Weight

A combination of supplemental weight data and recorded fuel quantity data was used to compute instantaneous aircraft weight. The passenger and cargo weight at takeoff and the aircraft basic weight were obtained from airline records corresponding to each recorded flight. Then the total of these weights was added to the recorded fuel weight at each event to compute aircraft weight at that time.

f. Stall Margin

The stall margin was calculated from indicated airspeed V_i and stall speed V_S with the following equation:

$$\text{stall margin} = V_i/V_S$$

The stall speed for each flap setting and aircraft weight combination was obtained from the 737 airplane flight manual (Reference 4).

g. Weather

From the Hourly Weather Observation data, the observation closest in time to each recorded arrival determined a VFR (visual flight rules) or one of four IFR (instrument flight rules) categories.

For ceilings above 1000 feet with visibility over 3 miles, the arrival was classified as VFR. Arrivals with ceilings below 1000 feet or visibilities below 3 miles were classified in one of four IFR categories with ceilings obscured, below 400 feet, between 400 and 1000 feet, and above 1000 feet. The flight rule categories are listed in Table 22.

TABLE 22. FLIGHT RULE CATEGORIES FOR APPROACH DATA

Code No.	Title	Ceiling/Visibility
1	VFR	over 1000 ft/more than 3 mi.
2	IFR-1000	over 1000 ft/less than 3 mi.
3	IFR-400 to 1000	400 to 1000 ft/all
4	IFR-below 400	below 400 ft/all
5	IFR-Obscured	Sky Obscured

The arrivals were classified in one of four wind factor categories based on the change in V_{REF} normally used by the airlines for approaches with ground wind conditions. Most airlines keep the airspeed reference pointer set at V_{REF} (1.3 V_{STALL}); but if strong winds are present, they recommend maintaining an airspeed above this to compensate for wind gradient and gust effects. For the wind gradient effect, they add one-half the wind value; and for the gust effect, they add all the gust value. As an example, if the wind is 18 knots gusting to 25 knots, they add 9 knots for the wind gradient and 7 knots for the gust effect so that the setting is V_{REF} plus 16 knots. If the total exceeds 20 knots, they add only 20 knots to the V_{REF}. When adding the wind gradient, they anticipate that the airspeed will decrease by this amount as the airplane nears the ground. If only the wind gradient is added, they allow the airspeed to decrease to the V_{REF} just before touchdown. If both the wind gradient and the gust effect are added, they retain only the gust factor to touchdown. The wind factor categories are listed in Table 23.

TABLE 23. WIND CORRECTION CATEGORIES FOR APPROACH DATA

Code No.	Title	Correction to V_{REF}*
1	V_{REF}+0-5 kt	add 0 to 5 knots
2	V_{REF}+5-10 kt	add 5 to 10 knots
3	V_{REF}+10-15 kt	add 10 to 15 knots
4	V_{REF}+15-20 kt	add 15 to 20 knots

* Add one-half of the steady-wind velocity plus the gust velocity.

h. Control Deflections

For uniformity in the data presentation, all control deflections were calibrated in percentage of full-scale deflection. Rudder, elevator, and aileron control deflections ranged from -100 to +100 percent. Stabilizer control deflections ranged from 0 percent at the full nose-up trim position to 100 percent at the full nose-down trim position. Flap positions are presented in the units shown on the cockpit indicator.

i. Engine RPM

The rpm measurements for each engine were calibrated to agree with the N_2 readings of the corresponding cockpit indicator. For the Events data, only one rpm channel is presented since it was assumed that all engines were at the same rpm levels during each event. Accordingly, the rpm's for engine No. 2 were used for the 737.

4. ILS Data

All recorded approach data with the VOR tuned to the ILS frequency of the arrival runway and with glide slope and localizer readings was classified as ILS data. Since the ILS was often turned on during VFR approaches when the pilot was not required to follow the beam centerline and, in fact, may not have paid any attention to the deviation indicator, the ILS data were separated by VFR and IFR categories. During processing, all IFR approaches were processed to yield the 23 parameters listed in Table 24, but the VFR approaches were only processed when convenient because they happened to be recorded on the same magazines as an IFR approach.

TABLE 24. TWENTY-THREE PARAMETERS USED FOR ILS DATA

Aircraft Weight	Flap Setting
Flight Phase Code	Roll (Bank Angle)
Arrival Airport Code	Pitch Angle
Arrival Runway Code	Heading
Flight Rule Code	VOR Frequency
Wind Factor Code	Localizer Deviation
C.G. Vertical Acceleration	Glide Slope Deviation
Taxi Speed	Computed Ground Speed
Pressure Altitude	Autopilot Mode Code
Indicated Airspeed	Engine N_2 Rpm
Dynamic Pressure	Time from Touchdown
Stall Margin	

Thus, the emphasis in the ILS data was the processing and presentation of all IFR approaches. In addition to the definitions given above for VGH and Normal Events data, the following paragraphs describe those definitions required for the ILS data processing.

a. Airport and Runway

The landing airport was determined from airline records corresponding to each recorded flight. The landing runway was determined from the approach heading, the ILS frequency (if used), and the data in the current issue of the DOD Flight Information Publication Low Altitude Instrument Approach Procedures (Reference 3).

b. VOR Frequency

The recorded VOR frequency was monitored to determine when the receiver was tuned to an ILS frequency (108.0 to 111.9 kc). The glide slope and localizer channels were switched off when VOR frequencies above 112.0 were tuned in. The ILS frequency was cross-checked against the published frequency for the arrival (Reference 11) to ensure that valid glide slope and localizer signals were being received.

c. Distance from Threshold

The ILS data comprises variable samples taken at the touchdown point, threshold, middle marker, outer marker, and at twenty-five distances from threshold at 2000-foot increments between threshold and 50,000 feet out. These samples, or ILS events, are listed in Table 25. One additional event, the maximum localizer overshoot, is included in Table 25. The definition of this event is given below.

Only two distances from threshold, the middle marker and the outer marker, were actually known in the recorded data. A third point, touchdown, was assumed to be 1000 feet down the runway from threshold. The times of all other ILS events, except the maximum localizer overshoot, were determined from the distances and times at touchdown, the middle marker, and the outer marker. To compute these times, ground speed was assumed to be constant between the middle marker and touchdown. From 50,000 feet to the middle marker, ground speed was assumed to vary linearly with a value of 1.2Vg at the outer marker and 0.8Vg at the middle marker, where Vg is the average ground speed between the two markers. The resultant computed ground speed was compared with the recorded airspeed to ensure reasonableness.

d. Localizer Deviation

The aircraft deviation from the localizer centerline in units of microamperes of receiver output was recorded during ILS approaches. Positive receiver output corresponded to a right CDI needle deflection which, in turn, indicated an aircraft flight path deviation to the left of the localizer beam centerline.

A 150-microampere reading represents a "two dot" needle deflection or a nominal 2-1/2 degrees deviation from the centerline. To provide a larger range of localizer deviations, a range of ±208 microamperes was chosen as the recorded data range since the receiver output was known to be linear over this range.

During each approach, the recorded localizer deviations were searched for the maximum localizer overshoot between the initial intercept of the beam centerline and the second crossing of the centerline. Additional constraints on the localizer overshoot required that the heading be within 15 degrees of the runway bearing and that the overshoot occur before crossing the outer marker.

TABLE 25. CODE NUMBERS, TITLES, AND DEFINITIONS FOR ILS EVENTS

Code No.	Title	Definition
1	Recorder Power On	Immediately following automatic recorded self-test
2	Localizer Overshoot	Maximum localizer overshoot following initial intercept of beam ℄
3	50,000 ft. from Threshold	Determined from computed ground speed*
4	48,000 ft. from Threshold	Determined from computed ground speed*
5	46,000 ft. from Threshold	Determined from computed ground speed*
6	44,000 ft. from Threshold	Determined from computed ground speed*
7	42,000 ft. from Threshold	Determined from computed ground speed*
8	40,000 ft. from Threshold	Determined from computed ground speed*
9	38,000 ft. from Threshold	Determined from computed ground speed*
10	36,000 ft. from Threshold	Determined from computed ground speed*
11	34,000 ft. from Threshold	Determined from computed ground speed*
12	32,000 ft. from Threshold	Determined from computed ground speed*
13	Outer Marker	Midpoint of recorded outer marker indicator lamp flashes
14	30,000 ft. from Threshold	Determined from computed ground speed*
15	28,000 ft. from Threshold	Determined from computed ground speed*
16	26,000 ft. from Threshold	Determined from computed ground speed*
17	24,000 ft. from Threshold	Determined from computed ground speed*
18	22,000 ft. from Threshold	Determined from computed ground speed*
19	20,000 ft. from Threshold	Determined from computed ground speed*
20	18,000 ft. from Threshold	Determined from computed ground speed*
21	16,000 ft. from Threshold	Determined from computed ground speed*
22	14,000 ft. from Threshold	Determined from computed ground speed*
23	12,000 ft. from Threshold	Determined from computed ground speed*
24	10,000 ft. from Threshold	Determined from computed ground speed*
25	8,000 ft. from Threshold	Determined from computed ground speed*
26	6,000 ft. from Threshold	Determined from computed ground speed*
27	4,000 ft. from Threshold	Determined from computed ground speed*
28	Middle Marker	Midpoint of recorded middle marker indicator lamp flashes
29	2,000 ft. from Threshold	Determined from computed ground speed*
30	Threshold	Determined from computed ground speed*
31	Touchdown	Identified from wheel spin-up on taxi speed channel 4

*Ground speed was computed from distances between threshold, middle marker, and outer marker and from times of touchdown, middle marker crossing, and outer marker crossing.

e. Glide Slope Deviation

The deviation of the aircraft from the glide beam centerline was also recorded in microamperes of receiver output. Positive receiver output corresponded to an upward glide bar deflection which represents an aircraft flight path deviation below the glide beam centerline.

A 150-microampere reading represents a full-scale "two-dot" glide bar deflection or a nominal 0.7 degrees from the centerline.

5. Taxi Data

As described above, the recorded ground operation was divided into four phases: preflight taxi, takeoff roll, landing rollout, and postflight taxi. This data was processed to extract all acceleration peaks, all taxi turns, and the distribution of time in taxi speeds. The twelve parameters listed in Table 26 were included in the reduced Taxi data.

TABLE 26. TWELVE PARAMETERS USED FOR TAXI DATA

Aircraft Weight

Flight Phase Code

Airport (Arrival & Departure) Code

Runway (Arrival & Departure) Code

C.G. Vertical Acceleration

C.G. Lateral Acceleration

Cockpit Lateral Acceleration

Indicated Airspeed

Taxi Speed

Heading

Engine N_2 Rpm

Time from Touchdown

a. Ground Acceleration Peak Definitions

For the recorded ground operation data, the c.g. vertical acceleration, c.g. lateral acceleration, and cockpit lateral acceleration time histories were each searched for peaks. The maximum or minimum acceleration value between consecutive crossings of the zero level was classified as an acceleration peak if it equalled or exceeded the ±0.1g threshold. The peaks were tallied in 0.1g intervals and classified by the corresponding values of weight, taxi speed, and heading, the flight phase, and the arrival or departure runway and airport.

b. Taxi Turns

During taxi, changes in heading of more than 15 degrees at turn rates above 3 degrees per second were classified as turns.

A turn was terminated whenever the rate of heading change decreased to below 2.5 degrees per second for a period of at least 5 seconds or when heading changed more than 5 degrees in a direction opposite to the turn direction.

During each turn, the maximum and minimum values of each of the three recorded accelerations were computed, the total heading change was computed, a code was added if wheel brakes were used during the turn, and the turn was classified by the values of heading and taxi speed at the start of the turn.

c. Taxi Speed

To provide accurate measurements at the lower taxi speeds, the taxi speed transducer was scaled for a range of 0 to 65 knots. The taxi data was classified in 5-knot taxi speed intervals. All ground operation at taxi speeds above 65 knots was placed in the 65-knot interval.

6. Flaps vs. Airspeed Data

During each extension and retraction of the flaps in the recorded UERS data, the maximum airspeed at each flap setting was extracted and tabulated. A value was tabulated for each setting passed through, even though there may have been no pause at that setting. Each flap setting was given a finite width of approximately 1/20 of the full-scale deflection to ensure that the DARS recorder would record at least one flap value at that setting during each traverse. All recorded airspeed values between the first recorded flap value in a setting and the first value outside that setting were compared to determine the maximum airspeed associated with the setting.

7. Mean and Standard Deviation Calculations

The arithmetic mean $\bar{X}$ and standard deviation σ were computed from the following equations taken from Reference 7:

$$\bar{X} = \frac{\Sigma(n)}{n}$$

and

$$\sigma = \frac{\Sigma f(d)^2 - (\Sigma fd)^2/n}{n - 1}$$

where
$\bar{X}$ = sample mean of X values
σ = sample standard deviation of X values
X = value of each measurement in sample
n = number of measurements in sample
d = value of midpoint of each class interval in sample
f = frequency of values in class interval d.

REFERENCES

1. Clay, L.E., R. C. Delong, and R. I. Rockafellow, Airline Operational Data From Unusual Events Recording Systems in 707, 727, and 737 Aircraft, Technology Incorporated, FAA Report No. FAA-RD-71-69, Federal Aviation Administration, Washington, D.C., September 1971.

2. DeLong, R.C., Commercial Aircraft Unusual Events Recording System, Report No. TI-273-71-3, Technology Incorporated, Dayton, Ohio, July 1971.

3. Low Altitude Instrument Approach Procedures, Department of Defense Flight Information Publication, Current Issues.

4. Airplane Flight Manual Boeing 737, November 1968.

5. Hunter, P.A., Summary of Center-of-Gravity Accelerations Experienced by Commercial Transport Airplanes in Landing Impact and Ground Operations, NASA Technical Note TN-D-6124, Langley Research Center, Hampton, Virginia, April 1971.

6. Carter, H.L., Revalidation of the Data Base Used in Establishing the Criteria for Simultaneous ILS Approaches to Parallel Runways Letter Report - Subprogram No. 150-502, Federal Aviation Administration, Washington, D.C., May 1970.

7. Arkin, H., and R.R. Colton, Statistical Methods, Fifth Edition, Barns & Noble, Inc., New York City, 1970.

8. Press, H., and R. Steiner, An Approach to the Problem of Estimating Severe and Repeated Gust Loads for Missile Operations, NACA Technical Note TN-4332, Langley Research Center, Hampton, Virginia, 1958.

9. Hunter, P.A., and M. E. Brazziel, Summary of VGH Data Collected on One Type of Twin-Engine Jet Airplane During Airline Operations, NASA Technical Note TN Technical Note TN D-4529, Langley Research Center, Hampton, Virginia, May 1968.